EVOLUTION OF PLANTS

by

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Fourth Printing
October, 1954

KNOWLEDGE SHARED MAKES PROGRESS

BURGESS PUBLISHING CO.
Minneapolis 15 - Minnesota

THE SCIENTIFIC ATTITUDE

A. S. Hitchcock

Scientific investigation is fundamentally a search for truth. It seeks to establish facts. At the outset one must distinguish between that which is a fact and that which is supposed to be a fact. One must divest oneself of all biased opinions, all preconceived theories or notions. In other words, one must approach one's subject, one's search for truth, with an open or unprejudiced mind. This mental condition is called the scientific attitude.

Not only should the student approach his subject with an open mind but he should maintain the scientific attitude throughout his investigation. He must guard against being influenced unduly by his own conclusions, that is, he must learn to abandon his own conclusions unreservedly if additional facts show them to be untenable.

This condition of open-mindedness is not natural with most of us but is the result of mental discipline. The average person is influenced by tradition and swayed by prejudice. The race has not yet outgrown the hampering effects of its savage ancestry; the mental attitude of our childhood days persists in our maturer years; and the average social environment retards rather than hastens the development of independent thinking. A mind permitted from infancy to develop originality and independence, taught to think clearly, and protected meanwhile from modifying influences of environment, would be the ideal one for scientific investigation, but such minds are so rare that they are practically non-existent. The conventional training received by a child at home and at school teaches him to think as others think, and to accept established customs without question. Social environment hinders the development of the scientific attitude because even the most enlightened peoples tend to accept things as they are and to resist changes in established customs. The average individual does not think independently on social, moral or political questions but accepts, often unconsciously and usually without much question, the opinions of the mass. Even scientists, when considering such questions may abandon their scientific attitude.

--From "Descriptive Systematic Botany," pp. 2 and 3, 1925

GENERAL PLAN OF THE COURSE

In this semester's study we shall trace the development of plants from their first beginnings to their present-day highest forms as represented in the sunflower and orchid types. We shall attempt to get a motion picture conception of the plant world instead of a still picture conception. We shall try to think of the present vegetation as merely a stage in plant evolution which has formerly presented a very different appearance and will no doubt in future ages be again quite different.

This manual is divided into chapters, one chapter to be studied each week. It is expected that you will have read the notes introducing the subject for each week before coming to the first meeting of the class. The laboratory directions will be carried out in the laboratory sessions. Drawings and notes from laboratory work will be preserved in the laboratory note book binder. In this are also bound the reports called for in the various chapters.

References for reading are given at the close of each chapter. It is expected that about four hours per week be spent in reading some or all of these references. Any notes you make on this reading are for your own use and not to be filed in your laboratory note book.

Before the various chapters listed below in the table of contents you may wish to write the dates for the respective weeks in which the chapters fall.

TABLE OF CONTENTS

The last three weeks will be devoted to the study of outdoor problems of plant life. Such material as the advancement of the season presents will be brought into the laboratory for close study and field excursions will be arranged for direct study.

SUGGESTED TOPICS FOR INDIVIDUAL REPORTS

Each student will prepare a report on a special topic of his selection in the form of a paper with accompanying bibliography and a short discussion of the topic before the class. In collecting material for your report make a complete bibliography. This must be included at the close of the paper. In giving an oral report summarize the main points under the topic, using brief notes on 3 X 5 filing cards. Following topics are only suggestions. You may choose one of your own, preferably one that bears on some experiences you have had that relate to plant life or one that reflects your special interest.

1. Early history of the study of Botany
2. Some pioneers of plant study
3. The life of Carl von Linnaeus
4. The life of Pasteur
5. Gregor Mendel and his discoveries
6. Luther Burbank and his discoveries
7. Early uses of plants for medicine
8. Herbals
9. Uses of plants by Chippewa Indians
10. Uses of plants by Sioux (or other Indian tribes)
11. Origin of our common fruits
12. Vegetational regions of Minnesota
13. The state forests of Minnesota
14. The state parks of Minnesota
15. Common spring wildflowers of Northfield vicinity
16. Spring wildflowers
17. Photographing wildflowers
18. Orchids and orchid culture
19. Color of flowers and color sense of insects
20. Yucca and Pronuba moth
21. Figs and Blastophaga wasps
22. State flowers of the United States
23. Indoor gardening
24. Common garden flowers
25. Choice and culture of street trees
26. Plants for landscape gardening
27. Landscaping the home grounds
28. The tropical rainforest
29. Vegetation of deserts
30. Plant life of Yellowstone
31. Our national parks
32. Our national forests
33. Arboreta of the world
34. Climate and tree rings
35. Plants and soil erosion
36. Tree shelter belts
37. Poisonous plants
38. Bacterial life
39. Seaweeds
40. Deep sea gardens
41. Diatomaceous earth
42. White pine blister rust
43. Wheat rust
44. Mushroom poisoning
45. Mushrooms as food
46. Ferns and their allies
47. Mosses
48. Fertilization of flowers
49. Seed dispersal
50. Wood used in making musical instruments
51. Wood and paper making
52. Growth and uses of cork
53. The cereals
54. The story of chocolate
55. The story of quinine
56. The coconut
57. Making an herbarium
58. Interesting greenhouse plants
59. Plant disease fungi
60. Our common lichens

GEOLOGICAL TIME SCALE

Era	Period	Years from Beginning of period to Present
Cenozoic Era, 4%	Recent	
	Pleistocene	1,000,000
	Pliocene	
	Miocene	10,000,000
	Oligocene	
	Eocene	20,000,000
Mesozic Era, 11%	Cretaceous	45,000,000
	Comanchean (Lower Cretaceous)	
	Jurassic	64,000,000
	Triassic	75,000,000
Paleozoic Era, 30%	Permian	90,000,000
	Pennsylvanian (Upper Carboniferous)	105,000,000
	Mississippian (Lower Carboniferous)	120,000,000
	Devonian	143,000,000
	Silurian	158,000,000
	Ordovician	195,000,000
	Cambrian	225,000,000
Proterozoic Era, 25%		350,000,000
Archaeozoic Era, 30%		500,000,000

The figures given in the third column are based on a conservative estimate made by Professor Schuckert of Yale University. More recent estimates by Urey, Lane, and others are considerably greater, approximately double, with estimates of 2,000 million for the Archeozoic and 1,100 million for the Proteozoic.

TABULAR VIEW OF THE PLANT KINGDOM

(After Shimer)

Division	Subdivision, Class or Order	Range	Common Name or Example
	(Angiosperms)	Comanchean to present	Oaks
	Dicotyledones		
	Monocotyledones	Comanchean to present	Grasses
	(Gymnosperms)		
	Gnetales	(Fossil Record Scant)	Ephedra
Spermatophyta	Coniferales	Permian to present	Pines
	Ginkgoales	Permian to present	Ginko
	Cordaitales	Devonian to Permian	Cordaites
	Cycadales	Permian to present	Cycads
	Cycadofilicales	Devonian to Jurassic	Neuropteris
	Lycopodiales	Devonian to present	Club-mosses
Pteridophyta	Equisetales	Devonian to present	Horsetails
	Sphenophyllales	Devonian to Permian	Sphenophyllum
	Filicales	Devonian to present	Ferns
Bryophyta	Musci	Tertiary to present	Mosses
	Hepaticae	Tertiary to present	Liverworts
	Fungi	Silurian to present	Fungi
	Algae	PreCambrian to present	Seaweeds
Thallophyta	Diatomeae	Jurassic to present	Diatoms
	Schizophyta	Pennsylvanian to present	Bacteria
	Myxomycetae	(No fossil record)	Slime molds

BOOKS INCLUDED IN THE READING REFERENCES

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Robbins, Wilfred W., and Weier, T. Elliot. Botany. John Wiley and Sons, 1950

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OTHER REFERENCES TO BE NOTED BY STUDENT:

CHAPTER I

INTRODUCTION: SOME SIMPLE ALGAE

The world of living plants that we see round about us has not always been as it is today. What we look on is but the last still picture in a long strip of motion pictures. Plant life is continually changing; it is never static. The changes are so slow that in the short period of a hundred or a thousand years very little change in the kinds and forms of plants would be perceptible. If we could however look back on the earth's vegetation a hundred million years, we would see quite a different picture from that of today. The seed plants would probably not appear in that vegetation. Instead, there would be forests of ferns, club mosses and horsetails, with numerous strange species of mosses, liverworts, algae and fungi making up the undergrowth. The numerous fossil remains of plants, many of which are now extinct, give us evidence from which we may piece out at least parts of the motion picture that represents the evolution of plant life.

When we speak of the evolution of plants we are at once confronted with the question of the origin of plant life on the earth. Concerning this we have a number of theories but proof is unavailable to establish any of them as fact. The Special Creation theory holds that plants were created by a Higher Creating Force. This puts the question outside the pale of scientific investigation and cannot lead to much progress in the solution of the problem. Some hold that life did not originate on the earth at all but that it was carried here from another planet. Meteors are said at times to contain moisture in their interiors when they strike the earth and the fact that some simple forms of organisms can withstand very high temperatures when in spore form contributes to the plausibility of this theory. Instead of answering the question of how life originated, this theory merely transfers it to another planet. Most scientists hold some form of spontaneous generation theory whereby inorganic substances came together fortuitously probably in the sea water of a cooling world and united in the correct proportions to produce the first bit of living slime or primitive protoplasm. This substance, having the unique characteristic of growth, increased in quantity and varied in its nature from time to time so as to produce in several hundred million years the multitude of species of plant and animal life that we know today. This process is the process of organic evolution. It is based on the incessant urge to grow and the continual tendency to variation, two characteristics inherent in protoplasm.

In the course of evolution of plant life variation brought on new forms, new species, new genera, new families from time to time. Many of the species were not capable of surviving long, others survived during long periods until changes in climate, competition of later newer species, or earth changes wiped them out. Many more species became extinct than survived. Of some of these we have a record in the fossil remains of the earth rocks. Some species were particularly well adapted to survive and have survived from the very early periods of plant evolution. Such species that have come through all the periods of change in plant life to the present day we may call "relicts". These relicts are useful to us in that they indicate the nature of the plants that were characteristic of those times from which they have come down to us. During the next two months we shall study a number of types of such relicts and from these we shall form an opinion of the nature of the evolution of plants from simple primitive forms to the present day highest seed plants. The general groups which we will study are Algae, Fungi, Liverworts, Mosses, Ferns, Fern Allies, Gymnospermous Seed Plants and Angiospermous Seed Plants.

The Seed Plants are the most conspicuous element in our present vegetation. There are approximately 133,000 named and described species of these. Of plants that do not produce seeds, the most of which reproduce by spores, there have been approximately 100,000 species described to date. It is safe to estimate that many more new species of this latter class will be discovered and described than of Seed Plants, so that eventually there will perhaps be 150,000 species of each kind making a total of 300,000 species of all plants. The most characteristic structure of the seed plants is the flower, and our study of plant types from the primitive to the modern will be designed to trace the history of the development of this structure from its first beginnings in the algae down to the most modern types in the Orchids or the Compositae.

BLUE-GREEN ALGAE (CYANOPHYCEAE)

Among the most primitive plants of which we have relicts today are the Cyanophyceae, simple, primitive, one-celled plants that grow in water or on moist soil and are perceptible to the unaided eye only when they occur in large masses. They contain chlorophyll in the cell but not arranged in a definitely shaped chloroplast. They do not as a rule appear green in color, as the chlorophyll is masked by the presence in the cell of a pigment of the anthocyanin group, known as phycocyanin. This is usually blue, though other colors occur. It is from this phenomenon that the group takes its name. No nucleus is present in the cell, but the chromatin material appears to be scattered among the cytoplasm in granular form. This indicates the primitive nature of the plants, as the organized nucleus of the higher forms is no doubt the product of a long course of evolution. In most cases the cells secrete gelatin which envelopes the cells with a protective envelope or a protective tubular sheath in the case of those forms that do not separate after division but cling together to make chains or filaments of cells. When a cell reaches maturity and conditions of growth are favorable, it divides into two cells by the simple process of fission, which is merely a splitting of the cell by the formation of a partition wall through its middle. No mitosis can take place as there is no nucleus.

These plants are reasonably common and can be encountered in almost any sample of ditch or lake water taken at random. They are also found in sea water and on moist soil and wet rocks. They constitute an important element of the food of fishes, as small crustaceans eat these microscopic cells and small fishes in turn feed on the crustaceans. In our northern lakes they often become so abundant as to color the water bluish green and make it objectionable for swimming. When they decay they impart a bad odor to the water. In reservoirs for drinking water they thus become a nuisance. They may be combatted by putting a trace of copper sulphate in the water. An abundance of these plants in lakes or ponds usually occurs after a hot spell in mid-summer and is known as "water-bloom". A species with red pigment is common in sea water (Trichodesmium erythraeum). It is responsible for the color of the Red Sea. Variously colored forms are common in the pools of hot springs such as those found in the Yellowstone Park, and they impart beautiful colors to some of these pools. They can live in water near the boiling point in the case of some species, others live in cooler waters, so that the temperature of the water can be roughly estimated by the forms of Cyanophyceae that live in it, the forms being distinguishable by their colors.

Since these plants can live in very hot water, it is an interesting speculation to suppose that they lived on the earth before it had cooled very much and that they have continued to exist in hot waters of geysers and hot springs. In these springs they are responsible for the formation of a friable chalky limestone known as travertine. They precipitate the limestone out of solution and deposit it in their gelatinous sheath. Calcium carbonate is more readily soluble in

water when the water is charged with carbon dioxide. As the plants take the carbon dioxide out of the water, the calcium carbonate is precipitated.

These plants have left us the most ancient fossils. In the Proterozoic rocks of the Northwestern United States and Canada nodular masses of concretionary limestone are common. Algal filaments have been found in these and it is thought that the algae are responsible for such formations. These fossils were long known as Cryptozoon before their true nature was understood. Some nine genera of Cyanophyceae have been identified from such fossils by the geologist Walcott. They are judged to have lived some 1,000,000,000 years ago. Associated with the algal cells are found bacterial cells, so that an equal age must be assigned to that type of plant.

In some genera the individual cells separate from one another as soon as they are formed by fission. Cylindrospermum is an example. In Gloeocapsa the cells separate but may cling together by adherence of their gelatinous envelopes for a time so that small groups of sister cells and cousin cells appear. In this genus the cross walls are formed parallel to two or three planes. In Merismopedia the resulting cells are held together for a long time, forming a sheet of tissue with cells grouped in square patterns. In many genera however the cross walls of cell division are always at right angles to the same axis, i.e., they lie in a single plane. The cells cling together after division with the result that a filament or chain of cells is formed. Such is the case in Nostoc and Anabaena, which are necklace-like, and in Oscillatoria and Lyngbya which present filaments of the same diameter throughout. These are held firmly in place by a common tubular envelope or rather firm gelatin, much as coins are held together in a paper coin wrapper. These filaments of Oscillatoria have a swaying motion which gives the genus its name. The cause of this movement of the filaments is not clearly understood but it is a surface tension phenomenon of the gelatinous envelope. Oscillatoria usually presents a bright blue appearance and may form masses of gelatinous matrix in which the separate filaments are embedded. Some of the species however seem to thrive in streams laden with decaying organic matter and in such situations probably take in organic nutrients from the surrounding water so that the photosynthetic process becomes less necessary and seems to have disappeared completely in certain species. Thus, they show similar characteristics as bacteria to which the Cyanophyceae are closely allied. Note for example that both groups lack the nucleus and that both multiply by fission.

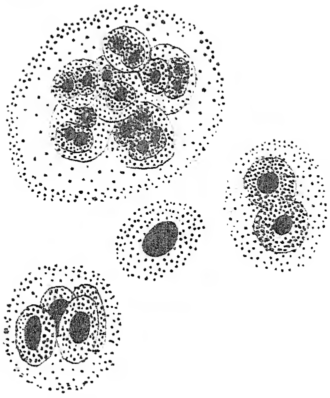
None of the filamentous forms of these algae has true branching such as we will find in the filamentous green algae. In some however there occurs the phenomenon of false branching. This comes about by the pressure of growing cells within a tubular filament becoming too great for the filament so that the row of cells buckles and forces itself out of the envelope and continues to grow so as to give the appearance of a side branch.

LABORATORY STUDIES OF CYANOPHYCEAE

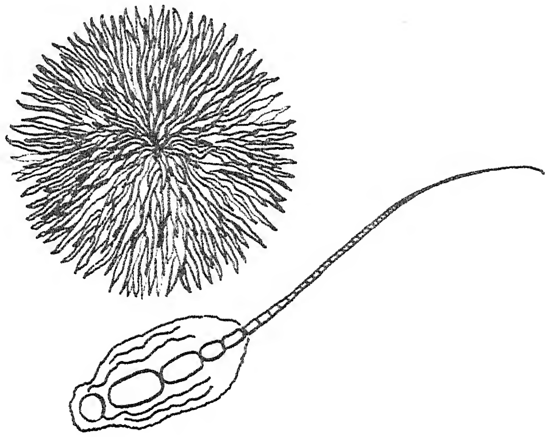
GLOEOCAPSA. This alga secretes gelatin so abundantly that it can be found by small masses of gelatin floating in water or coating the surface of moist rocks, on soil about springs, etc. Some of this has been preserved in formalin in the vial on your table. Mount a bit of the gelatin and observe the character of the cells, the nature of the secreted gelatin, and manner of the division of the cells. In how many planes does division take place? Note grouping of cells. How large are the largest groups you can find?

NOSTOC. This alga is similar to the preceding in that it is a strong gelatin-secreting organism. It is seen in moist situations commonly as small

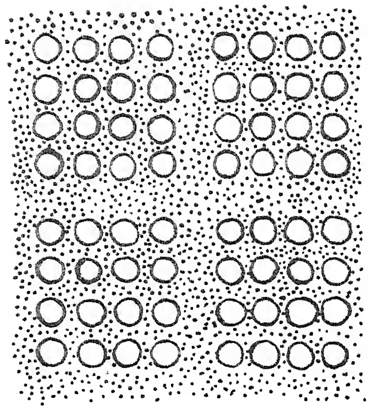
BLUE GREEN ALGAE



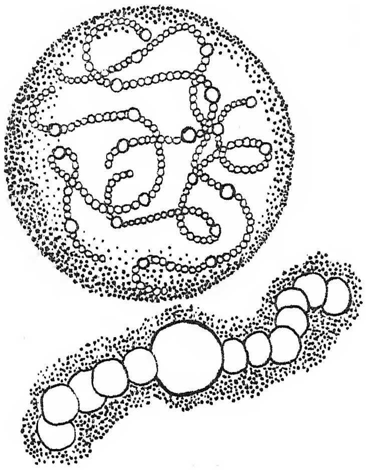
GLOEOCAPSA



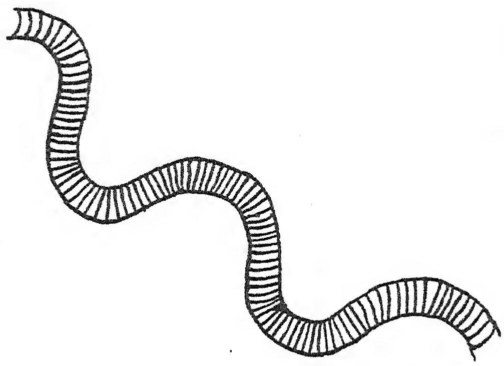
GLOEOTRICHIA



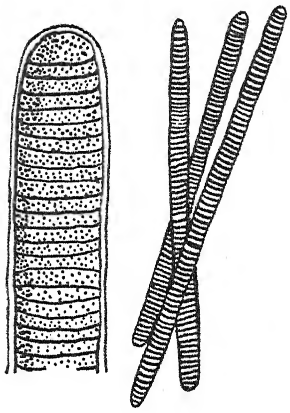
MERISMOPEDIA



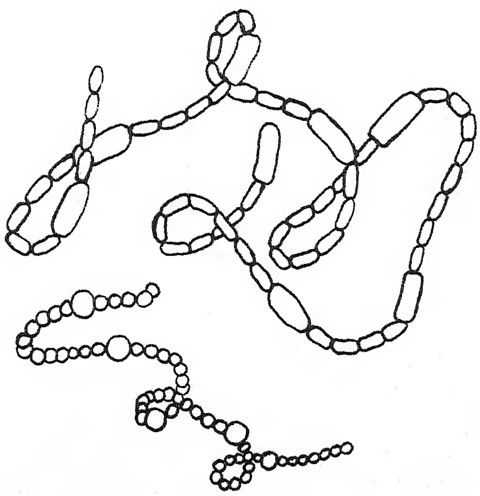
NOSTOC



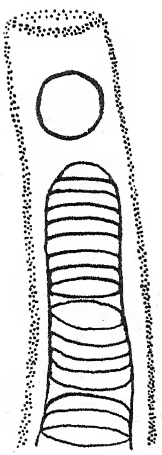
ARTHROSPIRA



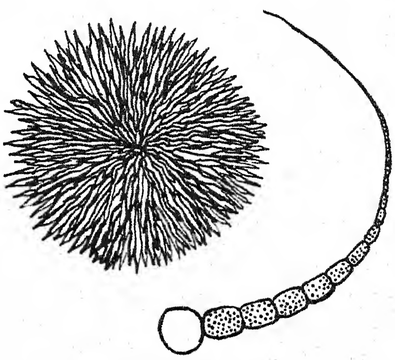
OSCILLATORIA



ANABAENA



LYNGBYA



RIVULARIA

balls of gelatin varying from very small to the size of a hazelnut. Lay one of the smaller gelatin balls on a slide and crush only slightly as you lay on the cover. Here again you find colonies, but how do they differ from those of Gloeocapsa? Why this difference? In the living state these plants looked bluish-green. The formalin has bleached them clear. Occasionally you will see a cell a little larger and rounder in a chain colony. At this cell the chain breaks easily, so that if you have crushed your cover down, it is not likely that the larger rounder cell will be in the middle of a colony but at the end or else floating entirely free. This cell is commonly called a "heterocyst"; it does not appear green like other cells in the living state.

Occasionally a group of cells is found that has its own gelatinous sheath inside the larger mass of gelatin.

ANABAENA. This genus is very similar to Nostoc. Study artificially stained colonies on the prepared slides.

LYNGBYA. A filamentous form found commonly in fresh waters and resembling Oscillatoria, in that the filaments consist of short cylindrical cells about the size of coins held in place by a gelatinous sheath, like coins in a coin wrapper. Your slide shows filaments that have been injured in handling so that the individual cells have been pushed along in the sheath, leaving parts of it empty. In some places a cell may be seen lying on its side. False branching is also seen in this slide.

GLOEOTRICHIA. The filament is in the form of a tapering chain or necklace. At the base are first a small round cell, the heterocyst, and then the large thick-walled spore, then follow the vegetative cells. What function do the spores serve?

RIVULARIA. One of the algae making Minnesota lakes bluish-green in summer. Note small globose masses in watch glass. Crush one slightly under cover glass and get an idea of the arrangement of filaments and to see more plainly the tapering filaments. Do you find a heterocyst at the base of the filament?

COELOSPHAERIUM. Colonies of globose cells held together in a mass of transparent gelatin. The slide on your table should show one or more of these crushed colonies.

MERISMOPEDIA. One of the "domino types" found commonly in fresh water. See permanent slide. The cell division walls are laid down parallel to two planes.

OSCILLATORIA. Arrangement of cells is like that of Lyngbya, but cells are smaller as a rule. The gelatinous envelope undergoes various constrictions, often spirally rhythmic, so that one sees an oscillating movement; hence the name. A second movement is often seen at the tip, which seems to turn sharply to one side. Sometimes filaments also creep lengthwise. Observe living material and prepared slides.

PLATE I. Make drawings of as many of the species studied as your time permits. Be sure to understand structure of all of them before the end of the period however regardless of how many you are able to illustrate.

THE FLAGELLATES

In any study of the early beginnings of our modern plants we must have a look at the group of one-celled organisms that have both plant and animal characteristics

and therefore remind us that these two lines of life forms very probably sprang from a common source. The organisms known as flagellates (flagellum, Latin word for whip) have one or more whip-like processes which they lash in an effort to bring food by stirring up currents and in order to move from place to place. The cell of an individual lacks a wall, but usually contains a membrane which may have embedded in it salts of silica and calcium. There is a nucleus and a contractile vacuole which contracts at intervals, presenting an appearance which made one of the early scientists studying the group, Ehrenberg, regard it as a primitive heart. The vacuole is however concerned with excretion of undigestible material which the organism has ingested. This ingestion of food seems to be an animal characteristic. Likewise, the motility is a characteristic usually associated with animals rather than plants. Many species contain a pigment spot which is light sensitive and receives the stimulus of too strong or too weak light which results in the organism moving into a zone of more nearly optimum light. But in spite of all these animal traits, many of the species possess chloroplasts and manufacture all or the most of their foods, a consideration which makes us claim them as plants.

The Flagellates reproduce themselves asexually by division of the cell along its long axis, each daughter cell receiving a nucleus, vacuole, chloroplast (if present), eyespot, and flagellum. One of the genera that has plant characteristics is Euglena.

LABORATORY STUDY OF EUGLENA

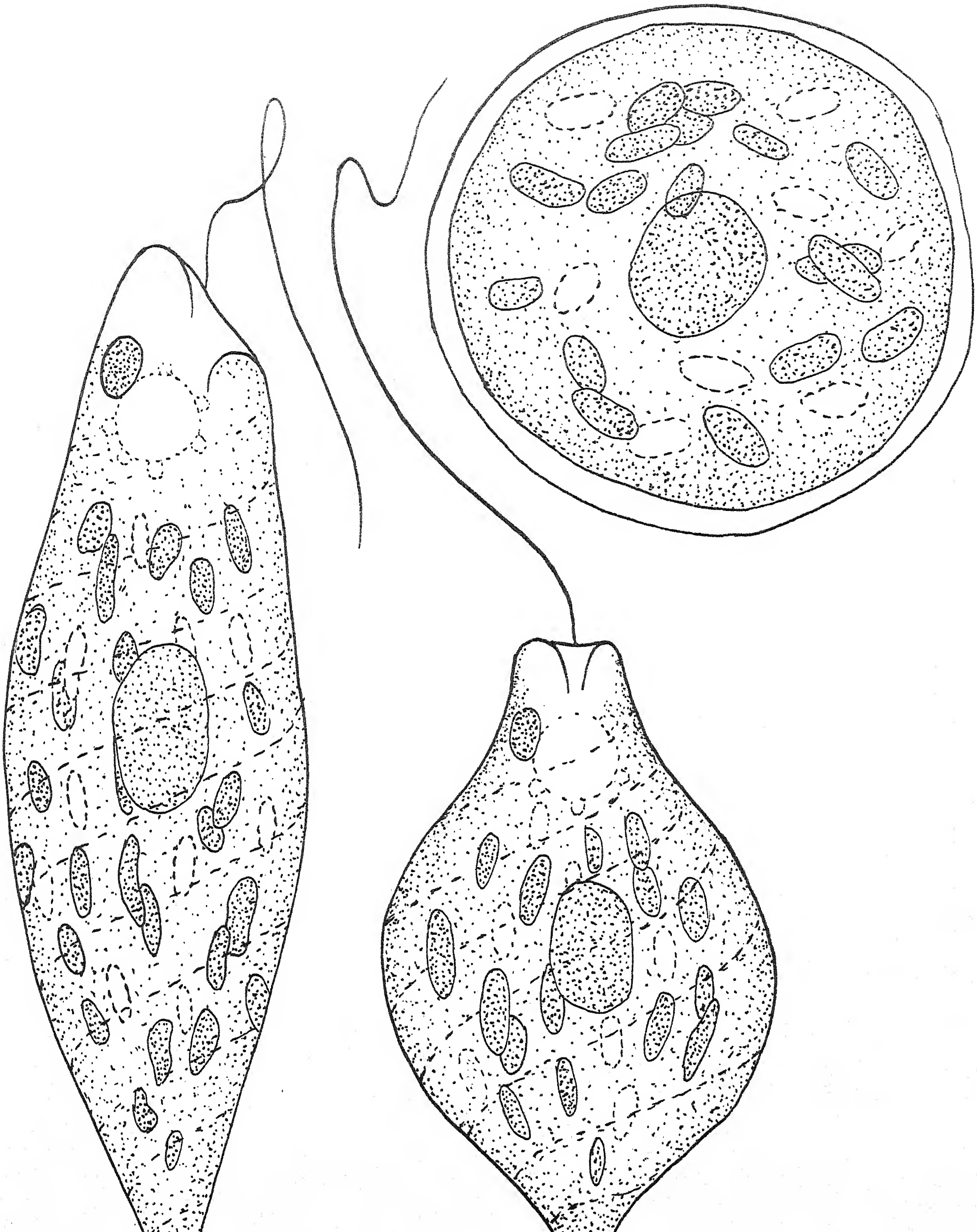
EUGLENA VIRIDIS is found commonly in ponds and ditches, often in such numbers as to give a green color to the water. Mount a drop of ditch water containing the organisms or a drop of pure culture solution of the same and study the living forms. What is the character of their motion? What changes in form do they undergo? What form does the dead or inactive body assume? Can you make out the red pigment spot? Its location in the cell? Function? At the same end (anterior) make out the pharyngeal pit, and extending from it, the flagellum. The flagellum is itself hyaline and is not easily seen without staining. Its lashings can however be detected by the motion of particles in the surrounding water. In some individuals it will be evident with rather weak light from the substage mirror. In what form does the chlorophyll exist? Is much chlorophyll present anteriorly? Can a nucleus be distinguished? What is the form of the body at the posterior end?

Run a drop of tincture of iodine under the cover glass. What effect has the alcohol of the tincture on the organisms? On the eyespot? The iodine may bring out certain details as the flagella, the nuclei, etc.

PLATE II. After a thorough study of Euglena viridis in life and from stained permanent slides, label the drawings on the accompanying plate.

REFERENCES FOR READING

Smith, pp. 272 - 277
Transeau, pp. 606 - 613; 621 - 624
Weatherwax, pp. 246 - 262 (A short survey of all the Algae).
Sinnott, pp. 463 - 468
Holman and Robbins, pp. 348 - 352
Emerson, pp. 172 - 175
Tiffany, L. H., Algae, the Grass of Many Waters. Pub. C. C. Thomas, 1938
This last is a short volume in attractive readable style that should be read in its entirety in the next four weeks.
Fuller and Tippo, pp. 537-545.



CHAPTER II

NON-FILAMENTOUS ALGAE AND DIATOMS

We shall now pay attention to a group of algae more advanced than the Cyanophyceae. This group known as the Chlorophyceae have a definitely organized nucleus and a distinct chloropast or chloroplasts. They lack the accessory pigment and therefore present a green appearance, hence the name Chlorophyceae or Green Algae. They inhabit both fresh and salt waters, though the species in salt water are few. They range in size and form from tiny microscopic one-celled plants to large sheets of tissue in Sea Lettuce and its relatives. Most of them are filamentous. Those we shall study in this chapter are not filamentous.

An example of one of the simplest of green algae is the Pleurococcus. It is a simple one-celled form living on moist soil, trunks of trees, old roofs, damp walls, and similar situations. While a single plant cannot be seen, masses of them together tinge the surface on which they live a green color. Under the microscope we see globose cells, containing vivid green chlorophyll and a nucleus. Division is by mitosis and a cross wall forms to divide the parent into two daughter cells. This cross wall splits and gradually the two cells are pushed apart as they each assume a round form. Sometimes they remain clinging together for some time and present a little colony of two to several cells. No sexual reproduction has been observed, a fact which attests to the primitive character of the plant. These are widely distributed in nature both in water and in damp situations various species related to Pleurococcus. Since they vary in different ecological environments, their classification is difficult.

Pediastrum is a plant that differs from Pleurococcus in that it does not live solitary but in definite colonies of 8, 16, 32, and sometimes 64 cells. The cells are arranged in a flat disc, the outer cells forming two sprocket-like protuberances each that make the whole look like a gear wheel. When time comes for cell division, the nucleus in each cell divides to form as many nuclei as there are cells in the colony. These nuclei then surround themselves with cell walls and the cells swarm for a time inside the wall of the mother cell and then attach themselves one to another to make the pattern of the parent colony. Escaping from the membrane of the mother cell, they grow into a new colony. Each cell in the old colony usually divides simultaneously with its neighbors, so that as many new colonies are formed as there are cells in the parent colony.

Scenedesmus is likewise a colony form, the colony consisting of four cells, elongated and attached to each other at their sides. At the four corners of the colony there is a spiny outgrowth in most species. Cell division takes place according to the plan of Pediastrum, each cell forming four new ones within itself which then unite into a new colony.

Hydrodictyon carries out the principle of the colony to a very great number of cells. The cells are elongated and attached to one another at their ends, three or four cells being attached at their ends. The whole makes a hollow mesh bag. There is no cell division after the colony is once formed. New colonies are started by the nucleus of a parent cell dividing to make as many as several hundreds of daughter nuclei, each of which becomes a daughter cell of a new mesh-bag colony.

A somewhat different line of algae than those described above is the type known as the Volvox and its predecessors. The simplest species in this group are one-celled motile organisms reminding one of Euglena. Like that plant they also have hair-like processes or cilia, two to each cell, by means of which they are able to swim about. They likewise have an eye-spot. While they multiply by mitotic cell division they may under favorable conditions manifest sexuality which

consists in two cells uniting to form a single cell, known as a zygospore. In higher forms as Volvox, the uniting cells are of two kinds so that we can say they manifest differentiation of sex into male and female elements.

Chlamydomonas is an example of the simpler unicellular solitary type of this group. It occurs in great numbers in quiet pools of fresh water, frequently being so abundant as to tinge the water green. If the water dries up, the cells lose their chlorophyll and form a red oily substance that fills the cell. Masses of those resting cells may color the mud a blood-color. One species lives in the cold waters from melting snow, multiplying rapidly on warm days so as to color the pools green. As the water freezes again, they go into the red resting stage and cause the phenomenon known to alpine travelers as "red snow."

A higher stage in the evolution of this type of algae is represented by Pandorina. Here the cells cling together in groups of 16, or in some species, 32 cells. Each cell has its eye-spot and its two cilia. All the cilia are directed outward and are lashed in unison so that the mass of cells rolls along under its own power. When division is to take place, this form differs from Chlamydomonas in that each cell undergoes division of its nucleus to produce 16 daughter nuclei, or whatever the number of cells in the parent colony may be. These nuclei escape from the parent cell wall, enveloped for a time in the membrane from the cell. Gradually they arrange themselves in the form of the family colony and escape from the membrane as a small new colony. A 16-cell parent colony would then produce at one time 16 new daughter colonies.

The highest stage of evolution of these colonial forms is reached in Volvox and its related genera. Here upwards of a thousand cells cling together as a single colony. The cells are arranged in the form of a hollow sphere which allows all the cells to come in contact with the surrounding medium to facilitate the intake of food materials in solution and the discharge of waste substances. The sexual process of reproduction is complex, certain cells specializing as egg cells and being fertilized by tiny cells (sperm cells) which are produced in great numbers in cells specializing as antheridia (specialized cells for the production of sperm cells). Similarly there is a complex process of asexual reproduction. In spite of high specialization of reproductive cells, the many vegetative cells have kept their primitive solitary character and there is no division of labor among the cells, each cell doing all that is necessary for its life.

LABORATORY STUDIES OF NON-FILAMENTOUS ALGAE

<u>PLEUROCOCCUS</u>. This alga causes the green color observed frequently on fences, bark of trees, roofs, etc., especially where these surfaces are kept shaded or moist. They are however not to be confused with small mosses that sometimes grow in these situations.

Some green bark from the north side of a tree has been kept moist and warm for several days. Pieces of this are supplied you in a watch glass. Scrape some of the green substance from the surface and mount on slide. Look for small green one-celled plants often adhering in groups. Under h. p. observe cell wall, granular green content and nucleus. Is there any arrangement in the groups? What causes them to adhere thus?

PLATE III. Draw enlarged several groups and detail of one cell.

PEDIASTRUM. This alga differs from the above in habitat, being found in ditch water, and also in the form of the groups of cells, as it has a definite number and arrangement of cells in a "colony" with variations. Seen in living condition, such a colony presents a beautiful appearance on account of the bright green color and the symmetry of the colony pattern. For our study, plants grown in quantity and fixed in chromic acid must be supplied you. They will show the cell contents somewhat shrunk and the green color considerably faded. How many different types of cell colonies can you find? See also permanent slides of Pediastrum.

On PLATE III draw detail of a perfect colony.

SCENEDESMUS. In preserved ditch water supplied you or on permanent slides find one of these 4-celled plants and study nature of cell contents and the four corner appendages (which however are absent in a few species).

On PLATE III draw detail of a plant.

HYDRODICTYON. This alga forms a large colony in the form of a hollow net, each mesh of the net being formed by individual cells. New nets arise by numerous nuclear divisions in one cell of an old net. The nuclei then surround themselves by cell walls and the cells unite end to end in such a fashion as to make a tiny new net. This escapes from the parent cell wall and grows to the parent size. In preserved material supplied and in permanent slides study nature of large cells of the net and look for new net formation.

On PLATE III illustrate a portion of a net colony.

CHLAMYDOMONAS. A solitary, one-celled motile green alga. In the active state the cells each have two cilia and an eye-spot. The single chloroplast has the shape of a cup with very much thickened bottom. When in the quiescent state, the cells are globose, the cilia withdrawn, and a reddish pigment is developed which obscures the other cell content. Some of the quiescent cells should be found clinging together in groups as a result of recent division or divisions.

On PLATE III draw detail of an active cell, as seen in median section and a quiescent cell.

PANDORINA. This is somewhat similar to Chlamydomonas, but the individuals cling together in colonies after division. The colonies are held together by a gelatinous matrix. How many individuals are in a colony? Note on the outside of the gelatinous mass, two small holes for each individual through which protrude the two cilia. Note that the colony is motile, and that in asexual reproduction, each cell may divide into eight, sixteen or thirty-two cells to make a new colony. In the permanent slide, look for young colonies in the process of formation.

On PLATE III draw an individual colony and a parent colony producing new colonies.

VOLVOX. This genus represents the highest point of development of the colonial plan in plant life. Living material and prepared slides will be supplied. The instructor will explain the structure of the colony and the nature of the life history.

REPORT I. Describe the colonial algae studied, tracing their evolution from simple to highest forms. Explain advantages and disadvantages of the colonial plan of plant body. Why are the Volvocales regarded as a "closed line" in evolution?

DIATOMS

This large group of one-celled plants is distributed widely throughout the salt and fresh waters of the earth. Not only is the group widely distributed geographically but in point of time we have evidence in great abundance of these plants having inhabited the seas in very ancient times. Their peculiar structure with a cell wall impregnated with indestructible flinty stone makes it possible to trace their remains in many regions of the earth. Deep beneath the surface of the earth in certain parts of Germany, in the Rocky Mountain region, in Virginia and in many other places extensive layers of the remains of these hard cell walls attest to the abundance of the organisms at a time when the areas in question were submersed beneath the waters of the sea. Other one-celled plants were no doubt equally abundant in the same periods of time, but having no durable cell walls they perished and we do not have evidence of their existence.

Hardly a drop of ditch water can be found that does not contain some of these plants swimming freely under their own power. Many other types are passive, lying on the surface of the mud in ponds or streams or carried along by the swifter waters of streams. The stones at the bottom of streams are often coated with attached forms so as to give a characteristic brownish appearance. The attaching stalks as well as the outer coating of such forms are gelatinous and this makes such stones quite slippery. Many a fall in crossing shallow streams on partly submersed stepping stones may be attributed to these diatoms. Certain quieter bays of the ocean have myriads of marine diatoms teeming in their upper surface waters. As they die their siliceous skeletons (principally silicon dioxide or silica of which glass is made) rain down to the bottom and in the course of long ages, such layers accumulate as did those which are mined from various parts of the earth today.

It is difficult to generalize on the shape of the individual diatoms, except to say that they are always beautifully symmetrical. Different species are disc-shaped, boat-shaped, cylindrical, needle-shaped, cushion-shaped, irregular, and some are even spiny. Once they attain maturity their form is set in stone and cannot change. The individual consists of a protoplast which usually has regular vacuoles. An irregularly shaped chloroplast is present but does not appear green to the eye because the chlorophyll is masked by a brown pigment characteristic of this group and therefore known as diatomin. A nucleus occupies the central part of the cell. The protoplast is from the first surrounded by a cell membrane and this membrane is gradually impregnated with silica much in the manner in which cell walls of woody tissue of higher plants are impregnated with cellulose and lignin. The protoplast does not completely surround itself with this shell, but pits or variously-shaped areas are kept free from the deposition of silica. On the surface of the shells there are markings appearing as wondrously etched lines or cross hatchings. These are so accurately placed in the patterns that lens grinders use them as test objects to determine the accuracy of lenses. The genus Pleurosigma is particularly useful for this purpose. In some species the silica is stained by cobalt compounds to give various tints of blue. The diatoms were then first to build stained glass windows.

The small size of these organisms must be kept in mind. A single individual is invisible to the unaided eye. A mass of these skeletons mined from the ancient beds makes an excellent scouring powder and is used commercially as an ingredient of some tooth pastes. It is sold under the popular name of diatomaceous earth. It is a white powder the color being due to the extremely small size of particles of glass just as the powder from a glass grinder's wheel appears white. Formerly it was used to hold nitroglycerine when pressed into sticks of dynamite.

The siliceous cell walls always consist of two halves known as valves which fit one over the other like the two halves of a pill box. When the cell divides, the two halves separate and each secretes a new half. The new half always fits inside the old so that in the course of several cell divisions they tend to grow smaller. They will finally become so small by this process that it becomes necessary to start anew. The shell sheds its small valves and increases much in size as a naked "auxospore". This auxospore then secretes large new valves upon itself.

LABORATORY STUDY OF DIATOMS

Living diatoms are supplied on stones brought from local creeks or lakes. Look for attached species, unattached immobile species, and motile species. The boat-shaped Navicula species are common. Can you make out the method by which they propel themselves?

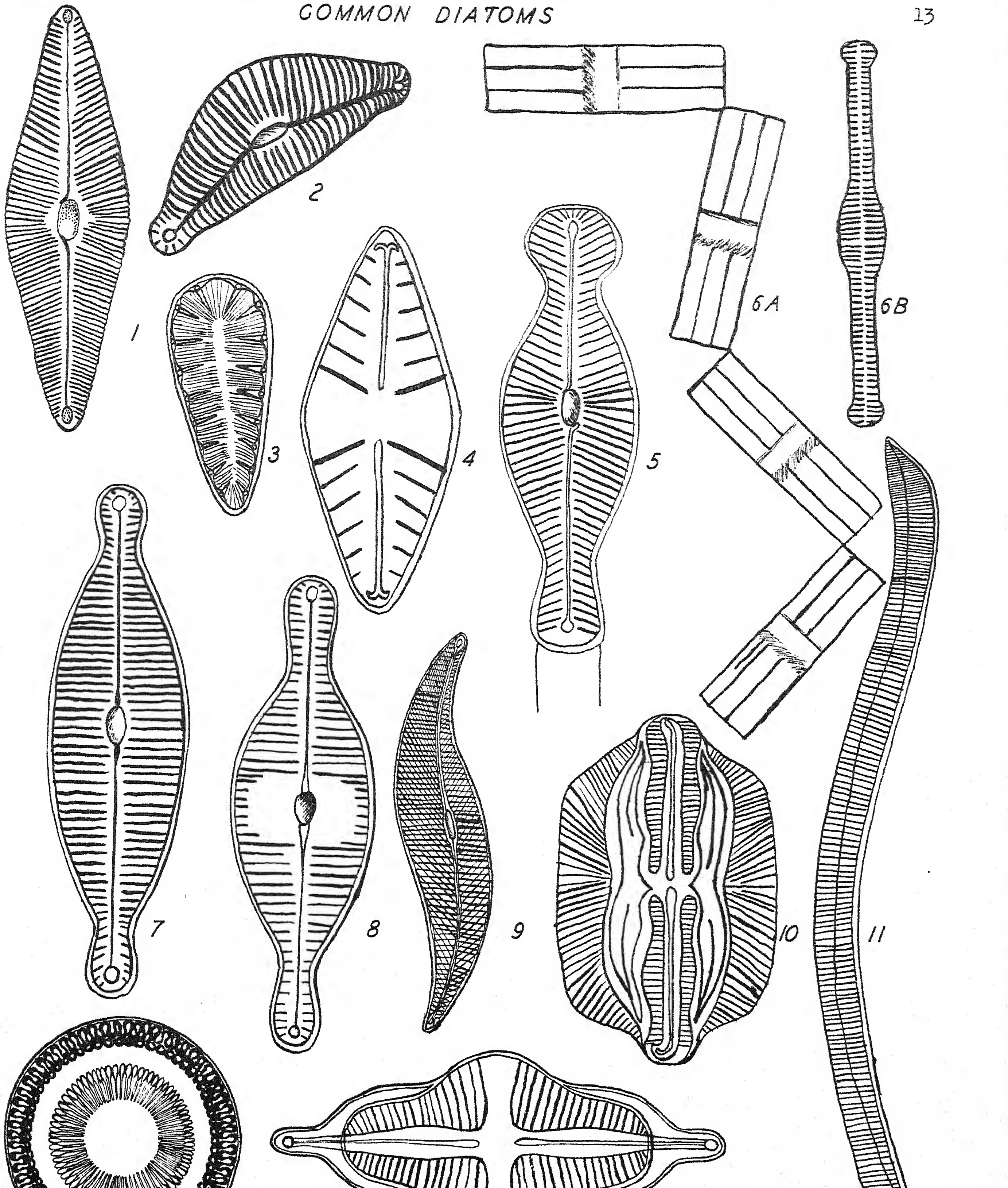
Preserved diatoms, most of which show only skeletons, are supplied you in preserving fluid and on permanent slides. Some of these you can identify from the photostat that shows drawings of named species. The demonstration microscopes show diatomaceous earth and marine diatoms. Note the cobalt-blue color of some of the marine forms. A bottle of diatomaceous earth is on your table. Mount a bit of the powder in a drop of alcohol and study microscopically. Remember that these are millions of years old.

Inspect the volume on Diatoms by the Reverend Wolle, which is on exhibit in the laboratory.

PLATE IV. Draw outlines of as many kinds of diatoms studied as time permits. At least one illustration should show living cell contents. Indicate both valve and girdle views wherever possible.

REFERENCES FOR READING

Smith, pp. 241 - 252
Transeau, pp. 625 - 627
Sinnott, pp. 468 - 478
Emerson, pp. 192 - 199
Remember also the previous reference to Tiffany, "Algae, the Grass of Many Waters."
Wolle, Rev. Francis, Diatomaceae of North America.
Fuller and Tippo, pp. 546-554, and 571-577.
Wilson, pp. 292 - 294



1. NAVICULA PEREGRINA 2. CYMBELLA CISTULA 3. SURIRELLA OVATA 4. NAVICULA PENNATA 5. GOMPHONEMA 6. TABELLARIA FENESTRATA 7. NAVICULA VIRIDULA 8. NAVICULA SPHAEROPHORA 9. PLEUROSIGMA 10. NAVICULA LYRA 11. SURIRELLA ANCEPS 12. CRASPIDODISCUS ELEGANS 13. STAURONEIS

CHAPTER III
FILAMENTOUS GREEN ALGAE

One of the most interesting genera of algae in this group is Ulothrix, a filamentous form that is unbranched and forms a hair-like growth on boulders, sticks and other objects submersed in fresh water streams or lakes. In the most common species the filaments do not grow more than one or two centimeters in length. The individual cells are cylindrical in shape, except that the tip cell is more or less semi-globose, and the basal cell which attaches the filament to the substratum is narrowed and elongated and at the base flares out in an irregularly shaped "hold-fast" which agglutinates firmly to the surface of the object to which it is attached. The filament grows by the division of cells, the mitotic spindles always lying in the same direction and the cross walls forming in the same plane. Each cell has a single chloroplast which is shaped like a napkin ring with undulate margins. A single nucleus is in the center of each cell.

Under certain conditions all of the cells in a filament may undergo a series of nuclear divisions producing 4, 8, 16, or 32 nuclei in a parent cell. These then surround themselves with cell membranes and escape from the parent cell wall as separate individual cells. By means of four cilia such a cell is able to swim about and to go into new territory, attach itself to a new substratum and grow into a new filament by means of repeated cell divisions and cross wall formations. Such a cell because of its animal-like motility, is known as a zoospore. Its function evidently is to help disseminate the plants.

Occasionally very small free swimming cells of the type described above prove not to be asexual zoospores at all but instead they will unite in pairs to form zygotes, thus assuming a sexual role. Such sexual cells we know as gametes. The root, gam, you recognize as meaning marriage as in the words "monogamy", "polygamy", etc. Special interest attaches to this phenomenon in Ulothrix because this seems to give a clue as to how sexuality arose in plants. We suppose that the normal method of reproduction in the lower plants was for long ages merely an asexual process through zoospores. Then there arose the process of two cells, possibly weaker smaller cells, uniting. Since this gave an advantage through increased vigor, it gradually became established as the normal process. It had the added advantage of combining two lines of inheritance and thus giving greater possibility of variation in the resulting offspring.

The zygote that results from the sexual union of two gametes in Ulothrix has four cilia, but its two nuclei fuse to form a single nucleus. It swims about like a zoospore and eventually attaches itself to a substratum and undergoes meiosis. It can be observed that filaments resulting from zygospores are larger and more vigorous as a rule than are those growing from zoospores.

Draparnaldia and Cladophora are two genera that resemble Ulothrix somewhat but they are larger plants and are branched. They are common in fresh water. Draparnaldia preferring to grow attached to stones in streams where the current is swift. These plants resemble Ulothrix in their method of reproduction, but sexual reproduction is not commonly seen.

Oedogonium differs from the preceding in having a more advanced method of reproduction. The cells in the unbranched filaments are several times longer than their diameter. Each cell has a single chloroplast which is in the shape of a cylindrical hollow net. The nucleus may lie in the wall layer of cytoplasm at the side of the cell.

Elongation of the filament does not take place by the division of all the cells as was the case in Ulothrix; only certain cells of a filament are set aside for division, and it is from the region of such cells that increase in length of the filament may take place. When such a cell divides, the one daughter nucleus lies near the end of the cell and the cell wall is laid down near it so as to make two daughter cells of quite different size. The smaller one however grows rapidly in length, and when full size is attained may undergo another division, and so until a dozen or more new cells have been produced. The actual number that have been produced by a cell may be counted by the number of ring-like remains of cell walls that remain, one from each parent cell wall.

Asexual reproduction by zoospores is seen at times. Each vegetative cell produces but a single zoospore, globose in shape and clear at the anterior end where there is no chlorophyll. At this anterior end one sees a ring or crown of many cilia. As these lash in unison, the zoospore moves through the water with a spinning motion. The zoospore settles down, attaches to a substratum and grows into a new filament.

Sexual reproduction is of the heterogamous type, i. e., sex is differentiated, the egg cell being large as but a single one forms from a vegetative cell. The sperm cells are quite small, several forming in short antheridial cells. They escape from the antheridia and swim by means of a crown of cilia similar to those of the larger zoospores. A sperm cell enters the side of the oogonium through a receptive spot where the wall is thin and fuses with the egg cell. The two nuclei fuse to form a single nucleus and the structure is an oospore, which corresponds to the zygospore of isogamous plants like Ulothrix. Here then we have an example of the second step in the evolution of sex in plants: the differentiation into two types of elements, which we may call male and female. The one cell provides motility but little food material, the other provides a large supply of food material but lacks motility. This really represents a case of division of labor.

Vaucheria (water felt) also reproduces asexually by large zoospores and sexually by heterogametes. It is commonly encountered in greenhouses where it grows on the moist soil of flower pots and on soil or gravel of benches. It may even coat the sides of flower pots. Of particular interest is the absence of cross walls in the filaments, so that all the cells are in a common tube, and the number of cells can be determined only by the number of nuclei. Such a plant is known as a coenocyte. One of the difficulties encountered by these plants because of this coenocytic condition is that when an injury of the cell wall occurs, the protoplasmic contents may be extruded before the protoplasm can replace the broken wall. In nature the plant occurs commonly on moist soil, on rocks in water, and at time is free-floating if the current breaks it loose. It is recognized by the harsh coarse feel of the plants as one rubs a mass between thumb and finger.

Many species show sexual reproduction fairly commonly. This is of the heterogamous type, large egg cells being formed singly in the oogonia and numerous small sperms being formed in the antheridia. These organs arise as side branches and are cut off by cross walls. The oogonium becomes globose with a beaked tip which is the receptive spot to receive the sperm cell. The sperm cells swim about by means of two laterally attached cilia and are attracted to the receptive spot of the oogonium by chemical attraction. One sperm enters and its nucleus fuses with that of the egg cell. The resulting oospore surrounds itself with a thick wall and undergoes a resting period. When favorable conditions present themselves after this period of rest, the oospore germinates and grows directly into a new coenocytic filament.

The zoospores formed are large and globose and are really coenocytic, many nuclei being present and the surface being covered with numerous pairs of cilia. It swims freely and eventually comes to rest growing out into one or more filaments. In this way the plants may establish themselves in new localities.

In all of these plants, the asexual spores, mostly zoospores, must be thought of as serving to multiply and disseminate the plants. Sexual reproduction may help to disseminate but need not multiply the number of plants. It does however afford a means of tiding the plant over a hard period of unfavorable temperature or drought. The zygote or oospore is usually built to resist adverse conditions. The walls are thick and the stored food materials are changed to an oily product which can last a long time in water without deteriorating. Zygotes or oospores usually sink to the bottom of the stream or lake at the approach of winter and germinate in the spring. Or in case of wet and dry seasons they serve to carry the plant through the dry period.

Besides the types discussed above there are numerous genera of green algae found in both fresh and salt waters, most of which have related structures and related methods of propagation. One group however must be mentioned because of the fact that the thallus or plant body is not filamentous at all but occurs in the form of a thin sheet of tissue. This is developed by the division of the cells in two planes instead of one, as is the case in the filamentous algae. Ulva (sea lettuce) and Enteromorpha are examples of this type of thallus. The latter is interesting because of the fact that the same species occurs in salt, brackish and fresh waters. In fact, the plants may be attached to the sides of an ocean steamer and still live when it docks in a fresh-water harbor. It seems to be able to adjust its osmotic pressure to suit the outside medium.

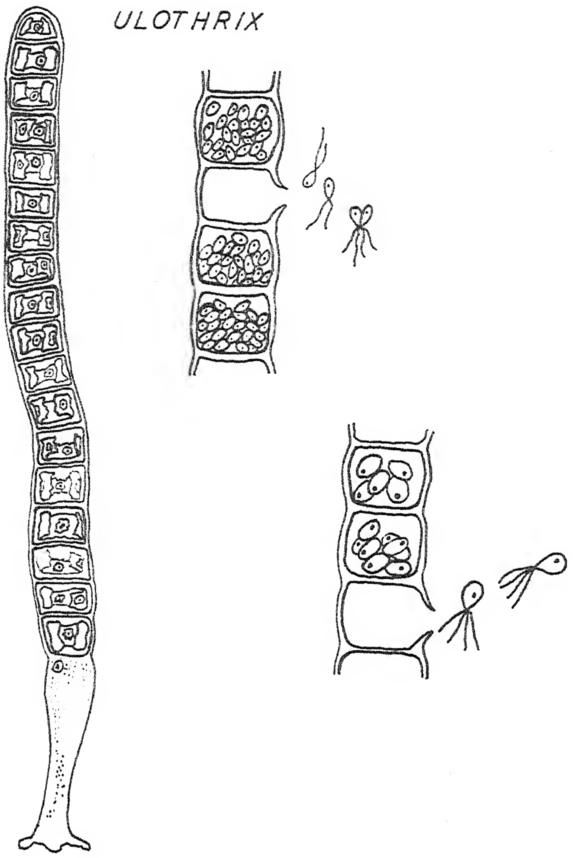
LABORATORY STUDIES OF FILAMENTOUS GREEN ALGAE

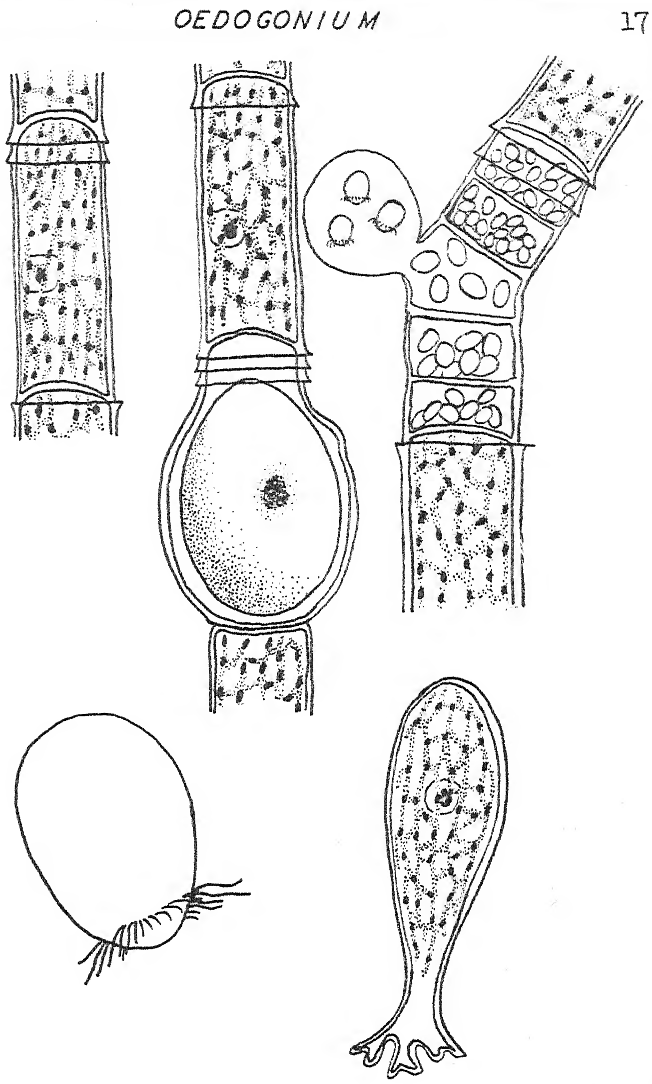
ULOTHRIX. Holdfast cells are at times difficult to locate in a mass of the filaments. If the material to be studied is attached to a stone or similar object, it is possible to scrape closely with a scalpel and remove a number of the holdfast cells. Sporangia either empty or with the 8, 16, or 32 zoospores still inside may be found in the preserved material or on permanent slide preparations. Similarly, gametangia may be found, but how may one tell whether such a structure is a gametangium or a zoosporangium? The swimming cells are hard to identify in live material because of the numerous swimming organisms of other species such as protozoa that are usually present in such material. These are best studied by first preparing as nearly pure cultures as is possible. Sometimes one may run across a young filament that has just started to grow from the zoospore or zygospore.

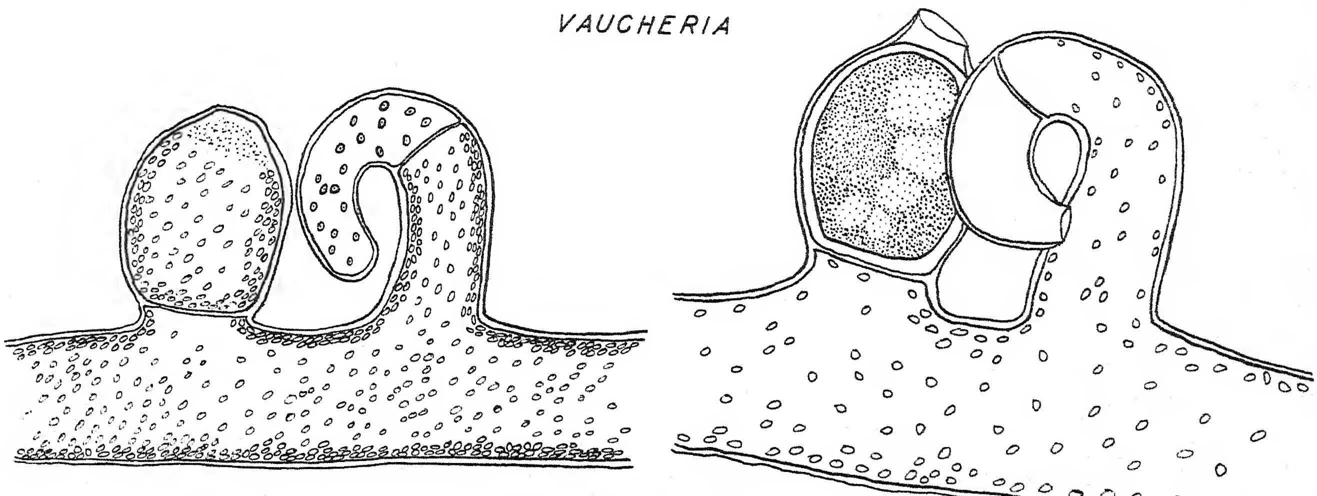
DRAPARNALDIA. This is worthy attention because of the beauty of its branching. It is particularly attractive in the green living state. Look for this in running water attached to sticks and stones in little clumps that feel jelly-like to the touch because of its gelatin secreting habit.

CLADOPHORA. How do the branch filaments arise from the main axis? Can you make out the nature of the chloroplast? This plant has holdfast cells similar to those of Ulothrix, though it more often breaks away and is free-floating.

OEDOGONIUM. Look for series of rings at the end of certain cells in which cell division has taken place. Oogonia are conspicuous and easily located. The antheridia are short cells usually occuring in proximity of the oogonia. Several are usually located adjacent to one another. The sperm cells are difficult to distinguish without following a special technique.


ULOTHRIX


OEDOGONIUM


VAUCHERIA

VAUCHERIA. Study carefully the coenocytic nature of the filament. What is the shape of the chloroplasts? Branching? In preserved material and permanent slides look for the sexual branches. If the receptive spot is open and the cell in the oogonium seems thick-walled it must be regarded as an oospore rather than an egg cell. Some of the antheridia will perhaps appear empty. Can you see where the sperm cells escaped? Two types of species are common. In the one, a single oogonium and a single antheridium appear on their respective branches. In the other type a single sexual branch is surmounted by one oogonium and this is surrounded by a number of antheridia which are on side branches that spring from the base of the oogonium. The instructor will try to present material of both types.

PLATE V. Show in diagrammatic drawings the nature of reproduction of these types: Ulothrix, Oedogonium, and Vaucheria. Label the drawings of these forms on the accompanying page of illustrations

REPORT 2. Write for your notebook a report setting forth how sexuality arose and how differentiation of sex developed, using as examples the plants you have studied.

REFERENCES FOR READING

Smith, pp. 252 - 257; 264 - 271
Holman and Robbins, pp. 354 - 356; 363 - 370
Emerson, pp. 201 - 203; 208 - 209
Robbins, W. W., and Pearson, Helen. Sex in the Plant World.
Robbins and Weier, pp. 313-318.

CHAPTER IV
CONJUGATING ALGAE

This large group of Green Algae takes its name from the characteristic manner of sexual reproduction in which two cells are united, usually by means of a connecting tube, and the content of one cell flows into the other with which it fuses to make a zygospore. Two large subdivisions of the group are the filamentous forms including the Mesocarpaceae and the Zygnemaceae, and the Desmidiaceae. The latter are usually solitary symmetrical cells of various patterns often quite bizarre.

As an example of the Mesocarpaceae we may pay attention to the genus Mesocarpus, a type of "pond scum" or "pond silk" growing as a free-floating form on the surface of quiet waters, or, in cold cloudy weather, sinking to the bottom. The filaments are unbranched and feel silky to the touch. A single filament consists of long cylindrical cells attached end to end, any cell in the filament dividing to form a new cell. The chloroplast is a broad flat ribbon which presents its flat side to the source of light when the light is weak but turns so as to present the edge when the light is strong. This adjustment reminds one of the adjustment that some leaves of higher plants undergo in an effort to secure optimum illumination. Such plants are known as compass plants because their edges are usually directed in a north-south direction.

In all of these conjugating algae no asexual reproduction occurs, other than the reproduction of cells by normal cell division. There are no specialized asexual spores. In sexual reproduction in Mesocarpus, two adjacent filaments that lie parallel put out protuberances from their cells which grow and are attracted mutually so that they come in contact in pairs. Where the protuberances touch, the cell walls are dissolved so as to connect the two, making a tubular passage from the cell of one filament to that nearest it in the other filament. Each of these cells must be regarded as a gametangium and the entire contents of each cell loses water and rounds up into a gamete. The two gametes are mutually attracted one to another and they begin to move toward each other, meeting in the middle of the channel. Here they fuse to form a zygospore, the tube enlarging at this point. All the cells of a filament usually form gametes simultaneously so that the series of conjugating tubes makes the two filaments like a ladder. Each round of the ladder is enlarged in the middle by a large round zygospore after conjugation has been completed. The zygospores develop thick walls and rest for a period of time when they germinate by the formation of four cells, only one of which grows into a filament.

It will be noted that Mesocarpus is strictly isogamous, since the gametes are alike morphologically and both present the same degree of motility. In the Zygnemaceae we find the beginning of heterogamy as the behavior of the gametes differs, one remaining stationary, the other moving through the conjugation tube and uniting with the other to form the zygospore in its gametangium.

As an example of the Zygnemaceae we may take Spirogyra, one of the most common pond silks. It resembles Mesocarpus except that the chloroplasts are quite different. From one to seven chloroplasts are in each cell. They are ribbon-like, the margin of the ribbons being undulating or even serrate. These ribbons lie in the wall layer of cytoplasm, winding about the circumference of the cell in spiral fashion. On the chloroplasts are seen at intervals greener spots which seem to be centers for starch manufacture, since staining with iodine after a period of sunlight leaves a halo of bluish stain about these "pyrenoids." Any cell in the filament may undergo division. When the nucleus and the

chloroplasts have divided, a cell wall begins to form from the outer wall inward in the manner of the closing of an iris diaphragm. No branching is ever found in the filaments of this group.

Conjugation in the genus of Spirogyra is of the "ladder-form" type in most species, though "close conjugation" is also found. In this latter type, there is no connecting tube between two neighboring filaments, but two cells within the same filament may unite their gametes, by a passageway formed around the partition wall.

Almost as common as Spirogyra is the genus Zygnema, differing principally in the kind of chloroplast. There is but a single chloroplast in each cell, shaped like a dumb-bell, with radiately spiny halves and nucleus lying at about the middle of what would correspond to the handle of the dumb-bell. Each half has a single prominent pyrenoid.

DESMIDIACEAE. The Desmids are principally solitary celled plants though a few cling together to form a loose filament. There are about a thousand species, found in quiet fresh waters, being particularly abundant in moorland ponds or bog ponds. A good place to look for Desmids is the small pools found in grassy bogs. The bottom of the pool should be stirred up and then the water put in a container to carry to the laboratory where it is put in a tall glass cylinder and allowed to stand till the suspended cells have gravitated to the bottom. If the water is then carefully decanted a fairly rich collection of the plants is found in the settlings at the bottom. None of these organisms has motility and there is no asexual reproduction other than normal cell division. The shapes of cells are quite varied in the different species, many of them assuming beautiful patterns that do not yield to description but must be seen to be appreciated. A common genus is Closterium which is shaped like a crescent moon. The two halves of the cell are mirror pictures, separated by an "isthmus" in the middle. The nucleus lies in this isthmus. In cell division the nucleus divides mitotically, then a cross wall forms across the isthmus. This wall now splits down its middle and the two halves are pushed apart by the turgor in the respective new cells. The bulging wall continues to enlarge and gradually grows into the form of the other half cell. Thus in every individual one half of the cell is always one generation younger than the other half. In all genera this mode of new cell formation prevails.

In the process of sexual reproduction two cells lying in proximity change their contents into gametes, one to each cell. The rounding up of these gametes seems to cause a pressure which causes the wall to split along the middle at the isthmus, so that the gamete protrudes and comes into contact with the gamete with which it is to mate. The two protoplasts fuse, the nuclei unite to form a 2X nucleus, and a heavy wall develops around the zygospore. This wall is often spiny or otherwise marked. The zygospore rests for a time, then germinates to form new plants.

In the symmetry of their forms many of the Desmids resemble the Diatoms. They however do not have siliceous skeletons surrounding their cells and the diatomin is lacking so that they are mostly vivid green in color. Desmids are eaten by crustaceans and other similar lower organisms which in turn serve as food for fishes. Thus through their chlorophyll they help feed a whole series of animal life.

LABORATORY STUDIES OF CONJUGATING ALGAE

Note appearance and characteristic silky feel of living Spirogyra. Study living filaments under low and high power. Compare the stained slides. The

species studied may differ as to number and arrangement of the chloroplasts, diameter of the cells, etc. The permanent slides are stained to show the nuclei and the cytoplasmic strands that suspend them to better advantage. The nature of the chloroplasts is better seen in living material. Note the pyrenoids in the chloroplasts. Is the margin of the chloroplast even?

Mount some filaments of preserved Spirogyra that is conjugating. The less they are disturbed in teasing them apart on the slide the better will conjugating filaments be kept together in the position in which they were in the water. Look for various stages in the process from the first growing out of wart-like protuberances from the gametangia to the complete thick-walled zygote. Such material as this often shows many zygotes and fewer of the earlier stages unless it has been collected at the time of beginning of conjugation. The permanent slides will supplement your study. How far along in its development is the conjugating tube when the gametes start rounding up into their characteristic shape? What becomes of the chloroplasts in the gamete cells? Do all the gametangial cells find mates to pair with? Are all cells in a single filament supplying or receiving gametes? Or may they be either? What becomes of a gamete in a cell that does not succeed in pairing? What is parthenogenesis? What can you learn of the nature of the cell wall of an older zygospore? How would you describe the shape of the zygospore?

CLOSTERIUM. Look for living Closterium plants in the ditch or aquarium water supplied you. The plants are easily identified by their crescent shape. Note the clear isthmus in the middle, the nature of the chloroplasts in each half, the vivid green pyrenoids on the chloroplasts. Study the stained cells on the permanent slides. Demonstration slides of Closterium lanceolatum will show a species of quite a different shape from the more common crescent-shaped species. Look for cells that have recently divided. They are recognized by the difference in size of the two halves. Some cells show also the process of division of the nucleus which precedes the division of the cell.

The various stages from division of the nucleus through the separation of the daughter nuclei into the two semi-cells with attendant cross-wall formation at the isthmus and subsequent separation of the daughter cells can be observed in the different stages shown by these slides.

The permanent slide labeled "Micrasterias" shows numerous desmids of this genus. In making a drawing of such an intricately symmetrical form as this it is advisable to fold a sheet of paper twice and to cut out 1/4 of the pattern of the plant with scissors. This pattern then can be used in tracing the outline of the plant. The same slide also shows the Cocklebur Desmid (Xanthidium). The two halves of this are somewhat spiny and triangular in form when seen from the end view. If a mixed collection of preserved desmids is supplied you for study, you can find still other forms which you will probably be able to identify with the help of the charts of Desmids supplied you.

Slides are shown under demonstration microscopes which show the conjugation of Cosmarium. The zygote is spiny-walled. Usually one may see the empty cells of the two gametangia which supplied the uniting gametes. The slide of Staurastrum likewise shows numerous spiny zygotes, some stained black, others stained red. On the slide may also be seen the empty cell walls of the gametangia, triangular in end view. What is the character of the tips of the spines on the zygote of Staurastrum?

In the mixed collection of Desmids and on slides supplied look for other species, such as Micrasterias, Cosmarium, Desmidium, etc. You may identify them

by use of the photographic chart on your table. Study particularly the intricate nature of the symmetrical pattern of Micrasterias.

Slides are supplied showing the conjugation of Cosmarium, one of the common species of Desmids. The dead gametangial walls are still seen near the zygospore. Note thick spiny walls that eventually surround the zygospore.

PLATE VI. Illustrate a single cell of Spirogyra showing all cell detail as seen in optical section. Should be at least 10 cm. long.

All stages in conjugation of Spirogyra.

Detail cell structure of a Closterium plant. A pair of recently divided cells of Closterium. Conjugation in Cosmarium or other species of Desmidiaceae.

REFERENCES FOR READING

Smith, pp. 257 - 263
Holman and Robbins, pp. 357 - 362
Emerson, pp. 203 - 204
Fuller and Tippo, pp. 562-565

CHAPTER V

SEAWEEDS (PHAEOPHYCEAE AND RHODOPHYCEAE)

A large group of algal plants that have persisted in seawater from the times of the early beginnings of plant life are the Brown Algae (Phaeophyceae) and the Red Algae (Rhodophyceae). They are known as seaweeds. Included with them are some marine species of Chlorophyceae. Those who have visited the deep-sea gardens with a glass-bottom boat at Catalina Island off the coast of California or some other similar place are familiar with the beauty of the filmy red "sea mosses", the larger brown kelps and the lettuce-like green algae. Those who visit the seashore on most coasts are familiar with the kelps that are washed ashore. At times great windrows are encountered. In New England the frugal farmers haul them upon their land because they contain nitrate and phosphate compounds useful as fertilizers. The Sargasso seas are great accumulations of Brown Algae with which are mixed many other kinds of plant and animal life. Some seaweeds are used for food by man. Such are for example the Gelidiums of the Japanese waters and <u>Chondrus crispus</u> (Irish Moss) gathered off the coasts of the British Isles.

The Phaeophyceae are as a general rule much larger plants than the Rhodophyceae, though small simple filamentous forms do occur. The so-called rockweeds which cover the rocks between high and low tide in most seas except the tropical ones are among the most abundant of seaweeds. In most of these the thallus is brown in color, varying to olive or quite dark, ribbon shaped and branched, varying from a few inches to a foot or more in length. The plants float upward when the water covers them but are prostrate on the rocks to which they are attached when the tide flows out. Some may be broken loose from their moorings and continue growth as free-floating forms. Such is commonly the case with Sargassum, an abundant genus that is seldom seen in attached form. In most of these plants gas bladders are developed which help buoy them up when high tide returns. This gives them more general exposure to light all over their surface.

Besides the Rockweed type of Phaeophyceae there are the larger forms known as kelps. Some of these grow into large ribbon-like thalluses up to 300 feet in length. They start as attached plants being fastened to rocks and other firm objects by means of "holdfasts" but often breaking loose and becoming free-floating. The plant body is usually ribbon-shaped with a mid-rib-like thickening running down its middle and being continuous below in a rope-like stalk which attaches to the holdfast. Laminaria, Agarum, Nereocystis, and Postelsia are examples of Kelps.

As to distribution, we may generalize broadly by saying that the Brown seaweeds tend to grow in shallower water usually between high and low tidemarks while the Red seaweeds tend to grow in deeper water. There are exceptions, of course, as some of the species of Red seaweeds grow in shallow waters, some even growing in our fresh water streams. Furthermore, we can generalize to the effect that the brown are found in colder waters while the Red tend to get into tropical waters more commonly. Abundant growths of kelps are common off the Canadian coast of the Pacific as far north as Alaska. It is in this region that the United States Department of Agriculture has long been experimenting with the collecting and processing of seaweeds in the manufacture of agricultural fertilizers.

While all these seaweeds have chlorophyll and are therefore autotrophic, only the Chlorophyceae present a green appearance. In the other two groups accessory pigments obscure the green of the chlorophyll, brown phycophaein in the Phaeophyceae and phycoerythrin in the Rhodophyceae. The red phycoerythrin often gives beautiful effects in varying tones of red color, so that these "sea mosses" have become the object of amateur collectors by the seaside. It used to

be a poor "whatnot" in the old-fashioned "parlor" that could not support display of a few sea shells and some mounted seaweeds. The function of the accessory pigments in these plants is said to be the neutralizing of the blue quality of the light as it filters through the water.

In the Brown Algae, asexual reproduction is carried on by zoospores usually produced in great numbers in sporangia. All the zoospores in this group of plants have two cilia laterally attached and, in swimming, one is directed forward, the other backward. In the Rockweeds, however, zoospores are not common.

Sexual reproduction varies from simple isogamy to very highly developed heterogamy. Ectocarpus, a simple filamentous plant, is a type of the former. The isogametes are similar to the zoospores, having two laterally attached cilia. They fuse in the same manner as the gametes of Ulothrix. In the Rockweeds, as for example Fucus, large egg cells are produced (eight in an oogonium) and numerous small sperm cells are produced in antheridia. The sperm cells have two laterally attached cilia. Antheridia and oogonia are borne in specialized depressions inside the thallus opening outward by a small mouth or "ostiolum." These are known as conceptacles and are found distributed over the tips of branches. When mature, both eggs and sperms are extruded into the seawater and numerous sperm cells swim about each large round egg cell. A single sperm cell finally effects an entrance into the egg. The egg thereupon loses its chemical attraction for sperm cells and all the other sperm cells cease to attempt an entrance. After fertilization the resulting oospore begins to grow by division of the nucleus to form two cells, then four, and so on until a pear-shaped mass of tissue results which gradually grows into a young thallus. The basal cell begins attachment to the rock or other substratum to form the holdfast.

In the Red Algae no ciliated cells are ever found. The sexual reproduction is complicated in most of the forms, though some show simple primitive characteristics. In general, two generations alternate, one generation producing egg cells and sperm cells which unite to form a 2N generation. This grows into a different type of plant which in turn after reduction of the chromosome number to the N condition produces non-ciliated asexual spores. These spores can produce only sexual plants. You will do well to remember this alternation of sexual N generations with asexual 2N generations as it occurs as a general phenomenon in higher plants.

The Seaweeds had less demand for changes from the primitive type during the course of evolution of plant life as the sea presented an environment that was subject to few changes. Consequently change and development of new structures took place in fresh water bodies more rapidly and on land it took place even more rapidly than in either fresh or salt water. Our highest types of plant life have been developed from land plants and the least progress is presented by these plants of the ocean waters. Another phenomenon that may be explained by the unvarying character of the seawater environment is the absence of a resting stage in the case of zygospores and oospores as no unfavorable seasons exist in the sea. In the ocean water, plant life can also exist much farther north and south than on land. Professor L. M. Gould reports relatively abundant plant life including many microscopic forms as well as kelps in the farthest south open waters near Antarctica. Land plant life, barring a few Lichens, is not found so far south.

LABORATORY STUDIES OF SEAWEEDS

<u>ECTOCARPUS</u>. Preserved material is supplied of this simplest and most primitive of Brown Algae. It is found distributed almost universally in the

shallow water along the seashore. In its filamentous character it resembles some of the Chlorophyceae. Which? Observe the monosiphonous filament, the cells composing it having easily distinguishable chloroplasts and nuclei that stand out in some cells without special staining. How do branches arise? Observe exact manner of attachment of the branches to main axis. In this material it is not uncommon to have diatoms attached to the filaments. Look for reproductive branches. The sporangium as well as the gametangium undergoes a rapid nuclear division to make large numbers of nuclei, which then become separated from one another by walls. We have then "plurilocular" sporangia and gametangia. Each little room or loculus produces a single spore or a single gamete.

FUCUS. Spread out a portion of the thallus keeping it moist. Note that it is flat, leathery and ribbon-like, and has a distinct midrib. The thallus is continued downward into the more slender and somewhat cylindrical stalk which ends in a flattened or irregular disk or holdfast. Note the dichotomous branching and the presence of large inflations or air-bladders. What is their function?

Scattered over the thallus you will see numerous small dots. In the center of each dot is a pore. (Use the hand-lens). These are cryptostomata. They have to do with the process of nutrition. Fine hairs are often seen to protrude from the pore. Upon what part of the thallus are these pores absent? At the tip of each vegetative branch is a very small elongated slit or depression, at the bottom of which is the growing point. A midrib extends up to each growing point. Note in the fruiting specimens the thick, club-shaped ends marked by numerous protuberances, and in the center of each protuberance a small opening, the ostiole. The protuberances correspond to large cavities, the conceptacles, in which the sexual organs are borne.

Cut thin cross sections of the flat thallus and mount in water. With l.p. observe the elongated elliptical outline of the section. Note the following arrangement of tissues: (1) the compact marginal wall of yellowish brown tissue or cortex. (2) This passes gradually into the less compact and lighter colored pith or medulla. This medulla consists of interwoven filaments.

Compare permanent sections with those you have made. From the two study cellular detail. Select the thinnest part of a section and with h.p. study in detail the epidermis or superficial layer, consisting of closely-packed and nearly isodiametric cells whose walls are thickened. Below the epidermis is a region of somewhat larger cells with more or less thickened, swollen, and stratified walls. Are chloroplasts present? This tissue merges gradually into a medulla, a loose tissue of interwoven filaments. The long cylindrical cells with greatly swollen walls are embedded in a mucilaginous matrix derived from the cell walls. If a section is found that has passed through a cryptostome, note the character of the surrounding tissues and fine hairs (filaments) which protrude through the pores. Beginning with the epidermis, draw a strip of tissue extending through the medulla.

Prepared slides supplied you show sections cut through the fruiting branch. One slide has male, the other female branch sections. On the slide marked female, find with l. p. a place in which a conceptacle has been cut through the center, i. e., through the ostiole. Note the spherical or flask-shaped cavity, the ostiole communicating with the exterior, the large dark brown bodies (oogonia), numerous hairs nearly filling the cavity and often projecting through the ostiole.

With h.p. observe the wall of the conceptacle, composed of closely interwoven filaments from which grow numerous hairs (paraphyses). Do the latter branch?

Note the oogonia which arise near the base of the hairs and are morphologically modified hairs. The young organ contains at least one nucleus, which by three successive divisions gives rise to eight. It is mounted on a unicellular stalk. Each of the eight nuclei surrounds itself by a cell wall and thus forms an egg cell. The egg cells in the mature oogonium are polygonal in form due to mutual pressure.

Study slide of male conceptacles and compare with those of the female. The antheridia are borne upon short branches somewhat aggregated in dense clusters. Unless the section is very thin, the individual antheridia cannot be so well observed, and if too thin the character of the branching cannot be followed. With h.p. observe the oval antheridia with granular contents borne upon short branched hairs. Each antheridium, when mature, contains many sperm cells that have two laterally attached cilia. Note the mode of branching of the hairs. Function?

Study the herbarium specimens of sea weeds displayed on the demonstration table.

PLATE VII. Draw a filament of Ectocarpus to show character of the cells and the nature of the branching. Draw a zoosporangium and a gametangium of Ectocarpus.

Draw habit sketch of Fucus, cellular detail of cross section of a thallus of Fucus. Cross sectional views of male and female conceptacles. Detail of one antheridium; detail of one oogonium. An egg cell and a sperm cell much enlarged.

In so far as time permits show habit sketches of Laminaria, Agarum, Chondrus, Polysiphonia, Nemalion, Rhodomelia, Delesseria.

REFERENCES FOR READING

Smith, pp. 278 - 301
Transeau, pp. 628 - 637
Sinnott, pp. 484 - 496. You will find the questions for thought and discussion helpful. Note those which you do not understand and ask your instructor about them.
Holman and Robbins, pp. 372 - 387
Emerson, pp. 183 - 192
Wilson, Chapter 20. This presents a good summary of the algae.

CHAPTER VI
BACTERIA AND MYXOMYCETES

All the lower plant forms that have a plant body not definitely specialized and lacking conducting tissues and multicellular sexual organs are known as the Thallophytes, or Thallus Plants. The term Thallus in its first meaning signifies a thread and was applied to filamentous algae. Its application gradually became extended to those plants related to the filamentous algae but having plant bodies consisting of membranes of tissues, ribbon-like growths such as those of the kelps and even such solid structures as shelf fungi, mushrooms, puffballs, etc. The Thallophytos as a group include almost as many species as the Seed Plants. They are however less conspicuous because of the small size of the most of them. They fall into two subdivisions, the Algae and the Fungi. These two subdivisions are clearly separated from one another on the basis of whether they do or do not have chlorophyll. No Fungi have chlorophyll; they are therefore heterotrophic, having to obtain their supply of food immediately or mediately from chlorophyllous plants. They are no doubt descended from algae, having once had chlorophyll but having lost it in the course of their evolution.

The Fungi are a very diverse group ranging in size from plants so small as to be hardly within the limit of visibility by use of the highest power microscope to such plants as mushrooms, mildews, molds, rusts, smuts, etc. For convenience we may classify all the Fungi in 5 classes:

Bacteria
Myxomycetes (Slime molds)
Phycomycetes (Alga-like Fungi)
Ascomycetes (Sac Fungi)
Basidiomycetes (Club Fungi)

The Bacteria differ from most other fungi by being strictly unicellular, although they may sometimes cling together to form loose colonies. The cells are very small ranging from about 0.025 mm. to as low as 0.0005 mm. in length. They are therefore the smallest of living things. They lack nuclei and very little detail of cellular structure can be made out. It is therefore difficult to classify them on the basis of their structure. More often they are classed on the basis of their behavior in mass. Particular food materials of known chemical constitution are acted upon by different species of bacteria in characteristically different ways and upon this much of the classification is based. For example some bacteria color the synthetic food material upon which they are cultured in the laboratory in a characteristic way, some grow into the food material in characteristic ramifying fashion, some cause it to liquify, etc. The organisms that cause the animal disease known as cholera cannot be distinguished from those that cause coconut bud rot in tropical America merely by a study of structure under the microscope. But the two behave quite differently.

As to shape of the cells, the Bacteria fall into the three divisions, Coccus forms (spherical), Bacilli (rod-shaped), and Spirillum forms (spiral or just curved). The Spirillum forms are always ciliated, the Bacilli may be ciliated or unciliated, the Coccus forms are never ciliated. The ciliated forms travel under their own power, the others depend upon being washed or blown about or being carried by other organisms.

The rate of metabolism and therefore the rate of growth is higher in Bacteria than in any other organisms. The small size of the plant body gives it an enormously large superficial area compared to its volume, which makes absorption of food correspondingly rapid since that is a surface function. If the food supply is available a single cell may give rise to billions of offspring in a

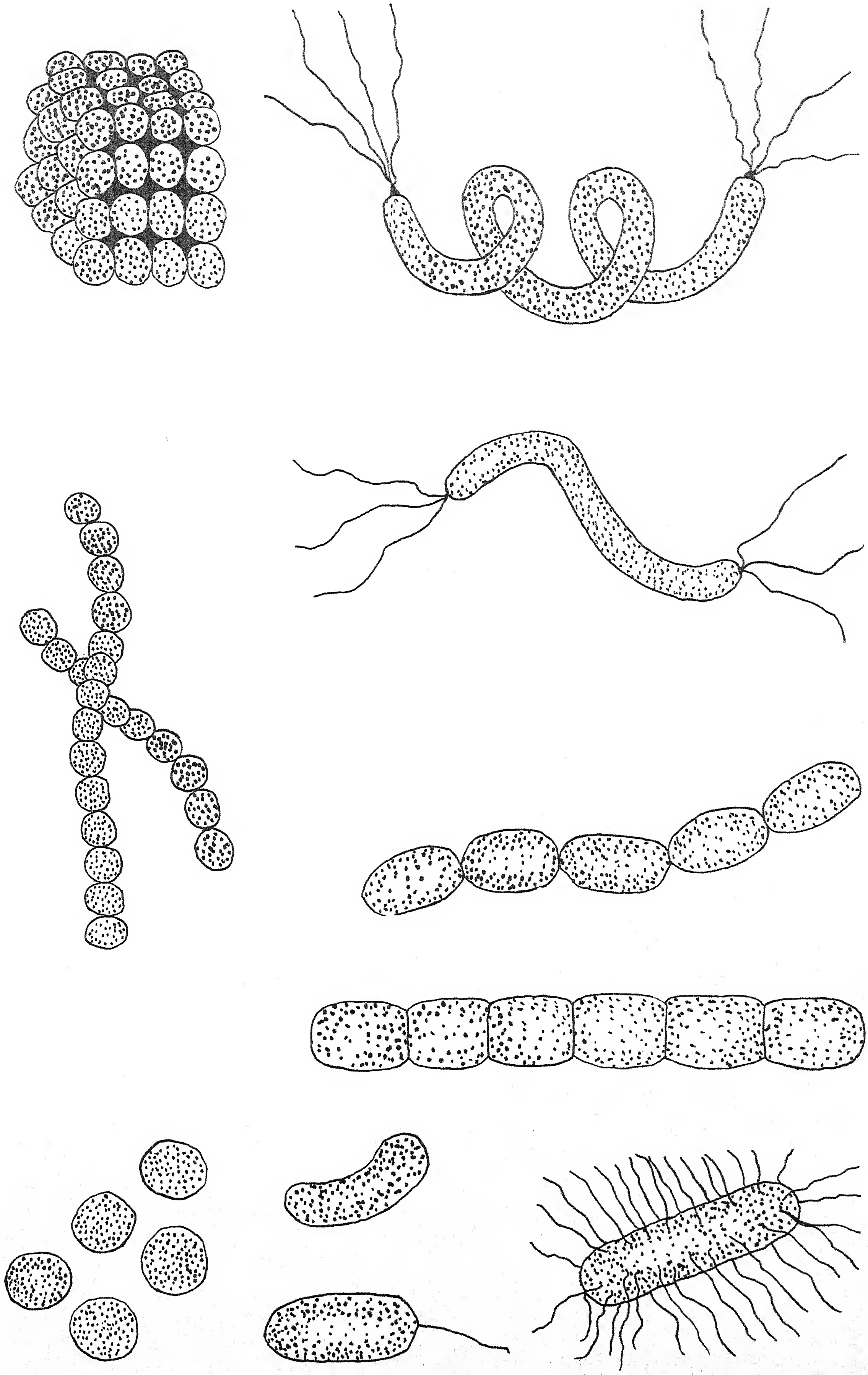
single day. Multiplication is exclusively by fission such as we found in the Blue-green Algae. The resulting individuals may grow to adult size in the course of a few minutes under favorable conditions and again divide. After division, bacterial cells often remain attached in chains, cubes, plates, or more complex colonies. At the onset of unfavorable conditions many species are able to draw the protoplasm of the cell together and form a thick-walled spore which can resist surprisingly high and low temperatures. They may in some cases resist being killed by the temperature of boiling water for hours. If however they can be induced to come out into the active growing form, such heat usually destroys them. Spores of this sort may in some cases live for years and retain their vitality. Indeed Dean Lipman of the University of California, Berkeley, maintained that he had established evidence that bacterial spores embedded in coal millions of years ago are still viable today. Such an extreme contention is not generally accepted by scientists.

Bacteria have a wide distribution throughout the world. It is easier to indicate where they do not occur than to enumerate their habitats. They do not occur in the healthy tissues of plants and animals, in chemical substances unfavorable to protoplasm, in the deeper layers of the earth or in the upper reaches of the atmosphere. Because they are so wellnigh universally present on the earth it was for a long time believed that life could originate spontaneously in preserved fruit, etc., that had not been heated to kill the existing bacteria. Exact knowledge of bacteria dates only from the last half of the preceding century. Their existence was proved by the great French chemist and biologist, Louis Pasteur, who labored under heavy opposition from medical men and fellow scientists before he could convince them that such small objects were actually alive and responsible for such important phenomena as fermentations, decay, silk-worm disease, anthrax of sheep, chicken cholera, etc. The work of Koch in Germany and of Lister in England supported and supplemented that of Pasteur of France. As recently as the period of the Civil War in our country hundreds of lives were lost by bacterial infections when they might have been saved by an elementary knowledge of bacteria and their control.

Relatively few of the bacteria are pathogenic, i.e., causing diseased condition of living plant and animal bodies. The few species that do cause disease have come to our attention so much that we are likely to associate bacteria only with the idea of disease. In fact there are relatively few diseases of plants caused by these organisms, the most of the plant diseases being caused by the higher fungi. The fireblight of pear, apple, and related trees is an example of a bacterial plant disease. The organisms penetrate the living tissues of the twigs and leaves, travel in the water ducts and cause a wilting of the twigs. Pathogenic bacteria are of course parasitic. The great majority of bacteria are saprophytic, living on dead plant and animal bodies from which they take their food and which they eventually reduce to the elemental stuffs from which the process of photosynthesis started to fashion them. This is called decay when it is carried to completion. If carried only to a half-way stage it is known as fermentation. All successful methods of preserving food depend on the defeat of bacteria in these processes. What are some of those methods?

Of particular interest to the botanist are the nitrogen-fixing bacteria that live symbiotically in the roots of leguminous plants where they form tubercles. These organisms are able to take the element nitrogen from the air and fix it into nitrate salts which can be used by the green plant on which they are symbiotic. Likewise, of interest are the nitrifying bacteria which take ammonia, the end product of protein decay and convert it into nitrite salts and these, in turn, into nitrate salts, the only way in which most green plants can utilize nitrogen.

TYPES OF BACTERIA



LABORATORY STUDY OF BACTERIA

Some garden peas were allowed to stand in a beaker of water for two or three days in the laboratory. Mount a drop of the water and under h.p. look for the rod-shaped bacilli moving actively about. This is a relatively large species and is ciliated, though the cilia are not visible unless specially stained.

Make a scraping from your teeth and examine for minute cocci and bacilli. If the teeth have not recently been brushed, particles of food and relatively large epithelial cells from the mucous lining of the mouth may appear in the scraping. Many kinds of bacteria live normally in the mouth.

Several prepared slides showing different species of bacteria are on your table. The special staining brings out detail not seen in living bacteria. You should see coccus, bacillus and spirillum forms.

Bacteria and Nitrogen Fixation. Clover roots with the nodules produced by Bacillus radicicola should be studied. Also the detail of a tubercle as seen in prepared slide. Note how the cells of the root cortex have become hypertrophied.

Petri dishes containing beef broth in agar will be supplied you. They have been sterilized under steam pressure and the cover should not be lifted to contaminate the sterile medium. Treat as follows:

1. Leave as a control. It must not be uncovered, of course, and should be handled as little as possible.
2. Uncover for 10 minutes so that dust particles of the room may settle down upon the agar.
3. Raise cover slightly and throw in a short hair from your hand or head.
4. You think of some other way of exposing the plate to bacteria.

Number and label these plates and allow them to incubate for two days in a very warm room. They will all be stacked together by the instructor; therefore your name should appear plainly on each.

Two or more days later examine the dishes for colonies of bacteria and molds. Make a transfer from one of the colonies obtained on one of your petri dishes to a culture tube of agar. Follow carefully the method and precautions explained by your instructor. Label the tube, giving number of your desk, date and source of inoculum. Allow to develop and observe at intervals.

Make a microscopic study of the bacteria and molds in the colonies obtained in your petri dishes.

Study the wall chart depicting different types of bacteria.

PLATE VIII. Draw the different types of bacteria as seen under h.p. Draw clover roots with bacterial nodules. Cross section of a nodule. Diagram of a petri dish showing colonies.

MYXOMYCETES. This second group of Fungi is quite different in its structures and habits of growth from the Bacteria. The type of work performed in causing decay and returning dead organic material to its original elements or simple compounds is however very similar. With few exceptions the plants are saprophytic. The number of species is very much smaller than that of Bacteria.

In the vegetative stage a myxomycete is a naked mass of protoplasm that creeps about over the decaying wood, leaves, or other organic matter in an

amoeboid fashion. It may be hyaline or colored buff, cream, lemon yellow, white or in brighter colors due to chemical substances included with the protoplasm. The mass of protoplasm is known as a "plasmodium". It may vary in size from minute particles to a mass as much as a foot in diameter. One might think that here was the most primitive type of life that had not descended very far from the original basis of life which we theorize originated by chance in sea water. A microscopic study, however, reveals well organized nuclei such as are not yet found in the Cyanophyceae nor in the Bacteria. Furthermore, when this protoplasmic stage reaches maturity, it undergoes in many species a most complex transformation into a highly developed sporangium. In the simplest cases, the mass merely becomes dry and encrusted on the outside. An examination shows the dry mass to consist of myriads of dust-like spores, each having a nucleus and being capable of forming a new plasmodium if it is blown onto a moist substratum. In higher types, the protoplasm rises into beautifully-fashioned sporangia, having basal stalks, columellae that extend through the sporangia proper, definitely organized walls and hair-like capillitia mingled with the spores. These must be seen to be appreciated. They can be found by carefully looking among the dead leaves and sticks of the damp forest floor and upon rotting logs. In some species they are beautifully colored.

Plasmodiophora brassicae is an example of a Myxomycete that is parasitic. It invades the tissues of cabbage plants and other members of the Mustard family. It causes hypertrophy of the tissues particularly of the root and crown of the plants. The disease it causes is commonly known as "Club Root of Cabbage" and is of economic importance. The plasmodial particles get into the cells of the host and at maturity turn into spores. When the host tissue decays on the ground the spores remain in the soil to attack the next crop. A field that is infected should not be planted to cabbage the next year. Another parasitic form, Spongospora scabiosa, causes one of the types of scab of potato tubers.

When spores of a Myxomycete germinate, the protoplasm creeps out of the cell wall and if sufficient water is present, it may put out a flagellum and swim about. In drier situations it merely creeps in amoeboid fashion. A number of these cells come together and form a beginning of a plasmodium which grows both by addition of other cells from the outside and by division of its own cells. In some cases sexual fusion of the free-swimming cells has been observed.

LABORATORY STUDIES OF MYXOMYCETES

Stemonitis is one of the most common of Myxomycetes. Its dark-brown sporangia may be seen in great clusters covering rotting logs or growing on dead leaves. Specimens are glued to the bottom of specimen boxes before you. How is the base of the stalk attached? What is the texture of the stalk? The sporangium proper has a thin wall when immature; when mature, this wall becomes brittle and crumbles away. Within, the spores are massed among the meshes of a branched reticulum called the "capillitium". The continuation of the stalk through the sporangium is called the columella. In old sporangia you will find few spores left among the capillitium as they have already been disseminated.

Note the preserved specimens of cabbage plants affected with "club root". Study nature of the infected tissue in the prepared slide supplied you. In what tissue of the root are the parasites found? Are they intercellular or intracellular?

Study the enlarged colored illustrations of sporangia of different species of Myxomycetes in the National Geographic Magazine, copies of which are in the laboratory.

PLATE IX. Draw habit sketch of several Stemonitis plants x 8. Draw enlarged part of a sporangium sufficient to show nature of columella, capillitium, outer wall and some spores held in the capillitium. Simple habit sketch of cabbage plant affected with Plasmodiophora and detail cross section of cabbage root with the parasite, as seen in prepared slide.

REPORT 3. Write for your laboratory note book a report setting forth the details of "The Nitrogen Cycle."

REFERENCES FOR READING

Smith, pp. 302 - 327
Transeau, pp. 531 - 540
Weatherwax, pp. 263 - 291
Sinnott, pp. 497 - 511
Holman and Robbins, pp. 388 - 406
Emerson, pp. 175 - 182; 210 - 213
Crowder, William. Marvels of Mycetozoa. National Geographic Magazine. Vol. XLIX, 4, pp. 421 - 443. April, 1926
Robbins and Weier, pp. 289-303
Fuller and Tippo, pp. 642-646

CHAPTER VII

PHYCOMYCETES AND ASCOMYCETES

The three higher groups of the fungi (Phycomycetes, Ascomycetes, and Basidiomycetes) differ from the two groups studied principally in that the basis of their structure is the hypha. A hypha is a filament similar to that found in many of the algae but lacking chlorophyll. In the lower group (Phycomycetes) this hypha has no cross walls so that the cells are coenocytic as was the case in Vaucheria. In the two higher groups on the other hand the hyphae have cross walls. Collectively the hyphae are spoken of as "mycelium." A mass of cottony mold or mildew which is familiar to the ordinary observer is spoken of as mycelium. When the mycelium becomes dense and the hyphae closely interwoven there results a more or less solid tissue, as is the case for example in the body of a common mushroom or puffball. Such a tissue is called a "pseudoparenchyma" since it superficially resembles a true parenchyma such as is found in all higher plant tissues but in reality it is only a mold-like mycelium that has become densely interwoven. A pseudoparenchyma stands in the same relation to a true parenchyma as a fiber rope does to a wooden stick.

The Phycomycetes seem to be the most primitive of the three groups of higher Fungi as they show in some forms a distinct isogamous sexual reproduction and there are more aquatic species among them than in the others. In fact they show a neat series of transitions from the aquatic to the aerial condition. The Saprolegnias (Water Molds) are common in all our fresh waters and cause the decay of dead plant and animal tissues such as aquatic plants, insects, fishes, etc. Some of the species are parasitic and are a menace to fish culture as the hyphae penetrate to the bodies of fish through the slightest wounds and vegetate in the tissues until the disease results in the death of the fish. In asexual reproduction, sporangia are formed at the tips of hyphae, the sporangia being cut off from the rest of the hyphae by cross walls. The numerous zoospores forming in such a sporangium escape through a pore at the tip and swim about by means of two cilia. From these new hyphae may grow. In sexual reproduction large round oogonia are formed on short side branches. In each oogonium are formed from one to several egg cells, depending on the species. The antheridia are formed in the tips of neighboring branches, but the sperm cells are not discharged into the water, but the tips of the antheridial hyphae themselves grow into the oogonium and deliver the naked sperm nuclei to the eggs. The resulting thick-walled oospores may rest for some time and upon germination grow directly into new hyphae. Sexual reproduction resembles that in Vaucheria closely.

As an example of a Phycomycete that has gotten out of the water and grows as a parasite in the moist tissues of higher plants we may take the "white rust" of members of the Mustard family. It ramifies through the intercellular spaces of the host plant, sending little knob-like "haustoria" into the host cells and sucking the nutrient substances from their cell sap. After a period of vegetative growth they begin to mass hyphae just below the epidermis of the host and cause the epidermis to puff up. This gives a white blister-like appearance to the surface of the plant which gives rise to the common name. The subepidermal mass of hyphae sends branch hyphae out at right angles to the leaf. These are conidiophores and from their ends are abstricted small globose cells containing a single nucleus each. These are known as conidia or conidiospores. They continue to form in succession until a chain of these spores results. As the host epidermis dries out and crumbles, these powdery masses of conidia are blown by the wind to other plants which are in turn infected by the "white rust". Sexual reproduction in this plant is not unlike that of the Saprolegnias, the sex organs being formed within the host tissues.

We must yet have a look at a third type of Phycomycete, a saprophyte which flourishes on dead organic matter. We shall choose the very common Black Mold of

bread (Rhizopus nigricans), known to every householder as forming a black growth on moist stale bread and also the air of an average atmosphere is practically never free from some of the minute dust-like spores of this fungus. Some of the spores settle on bread and if there is enough moisture present, it germinates, growing out into spider-web-like hyphae that absorb food from the bread and grow and ramify until the bread may be interlaced with this mold. Being white, it may not be visible at all and most of us have frequently eaten bread in this condition.

After the hyaline mycelium has flourished for some time in the bread it sends up hyphae from the surface for a distance of about a millimeter. At the tip one of these hyphae begins to swell out until a round dome-like globose enlargement results. This is cut off from the stalk part by a cross wall that bulges up into the interior of the globose part. This latter is the young sporangium. Its nuclei undergo numerous divisions and eventually hundreds of nuclei are present. Each surrounds itself with a membranous wall. The wall becomes thicker and thicker and eventually turns brown and then black. The sporangium filled with these numerous black-walled spores thereby itself assumes a black color. Numbers of these sporangia together on the bread account for the black patches of mold on the bread. It is interesting to note that the mold itself is not black at all but that the black is due entirely to the mass effect of the myriads of highly pigmented spore walls. The wall of the sporangium dries and crumbles thus releasing the black spore dust to air currents. No wonder that the average atmosphere has these spores always normally present.

There are two strains of bread mold, a plus and minus strain, or we are justified in calling them female and male strains respectively. Usually only one strain is encountered in a particular kitchen so that sexual reproduction is not found. If however mold from the two strains is brought together, sexual reproduction not unlike that of Mesocarpus is encountered. Two club-shaped hyphal branches come in contact at their tips. The mass of dense protoplasm in the tip of each of these branches is cut off by a cross wall to form a gametangium. The walls separating the gametes are dissolved and the two fuse in the process of conjugation to form a zygospore. This develops a thick spiny wall and rests a long time. Upon germination it sends out a hypha that develops a sporangium like that described above.

The "Downy Mildews" are another group of parasitic disease-producing Phycomycetes. Downy Mildew of grape may be taken as an example. Small sporangia (formerly known as conidia but probably best not classed with those structures) are blown from infected plants to healthy leaves. In the surface film of dew or rain, the sporangium gives out several zoospores which swim by means of two cilia. They penetrate into the leaf tissue by way of the stomata. In the intercellular spaces they grow into branching hyphae that grow throughout the leaf sending knob-shaped haustoria into the host cells. When fruiting time comes the mycelium sends a long hypha out of a stoma. This branches abundantly and at the end of each branch there develops a sporangium such as that which first came to infect the leaf. The sporangium produces zoospores. Young fruits of grape and stems as well as leaves are affected. The mold may grow on surface as well as in the interior, thus giving a downy appearance.

Of special interest in connection with this parasite is the fact that Professor Millardet of the University of Bordeaux, France, discovered the efficacy of "Bordeaux mixture" as a fungicide while combating this disease.

Similar in most respects to the life history of <u>Plasmopara viticola</u> is that of <u>Phytophthora infestans</u>, causing "late blight of potato." The life history is

enacted very rapidly in this organism under favorable conditions and the disease becomes epidemic. The famine of Ireland in 1845 and subsequent years was due to long periods of damp muggy weather so that the disease spread among the potato fields of Ireland, caused much starvation and let to one of the greatest exoduses from that island to the United States. Many of our Irish-American families trace their advent to the period between 1845 - 1850. Not only that, but the potato shortage also forced England to enact the Corn Laws. Thus we see how an apparently insignificant fungus like this can take a role in shaping the destinies of nations.

LABORATORY STUDIES OF PHYCOMYCETES

Saprolegnia can usually be obtained by bringing lake or ditch water into the laboratory in a vessel and putting some house flies or other insect bodies into the water. In the course of several days a white cottony mold appears. The instructor will supply such cultures for your observation. Infection came from the zoospores which are usually abundant in such waters. Study the mycelium under magnification. Cross walls? Look for cylindrical sporangia at the tips of some of the hyphae. Are zoospores visible in the sporangia? See also permanent slides of hyphae with sporangia.

Observe the mycelium of bread mold growing on moist bread. Branches of the mycelium penetrate the substance of the bread and absorb foods which are transported to the remaining portions of the plant.

How must the solid foods of the bread be changed before the fungus can absorb them? How does the fungus bring about this change? Could this take place if the bread were very dry?

Examine the culture in detail. Note the erect branches bearing globular sporangia at their tips. Near the base of these branches note the rhizoids which are frequently attached to the dish in which the cultures are growing. How is food transported to the sporangia?

Break open a sporangium. What does it contain? Into what would the spores develop? What is the color of the young spore wall? Of the mature spore wall? Determine from sporangia of different ages how the columella arises and develops.

In the prepared slide find stages in which the swollen branches (progametes) from the mycelium are in contact at their tips. Find others of these showing a transverse wall at the tip of each. Find stages in which the wall between two terminal cells (gametangia) has partly or wholly disappeared. Find still other later stages in which the gametes have fused and the zygospore wall is beginning to thicken. Note that in some mature zygospores the outlines of the two gametes is still apparent. Are the two usually of equal size?

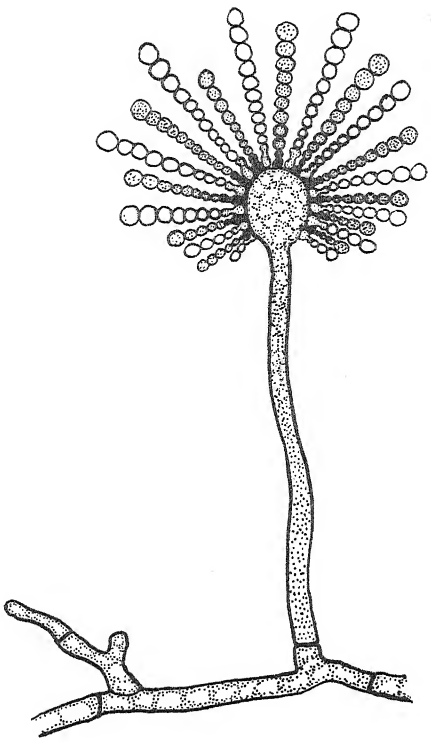
On the demonstration table, study the museum specimen of Downy Mildew of Grape and in the demonstration scope look for the haustoria sent by the mycelium into the host cells. Fix the character of these in mind so that you can describe them later if called upon.

PLATE X. Bread mold: Draw a bit of mycelium, showing rhizoids, stolons, erect branches, sporangia, and mature spores.

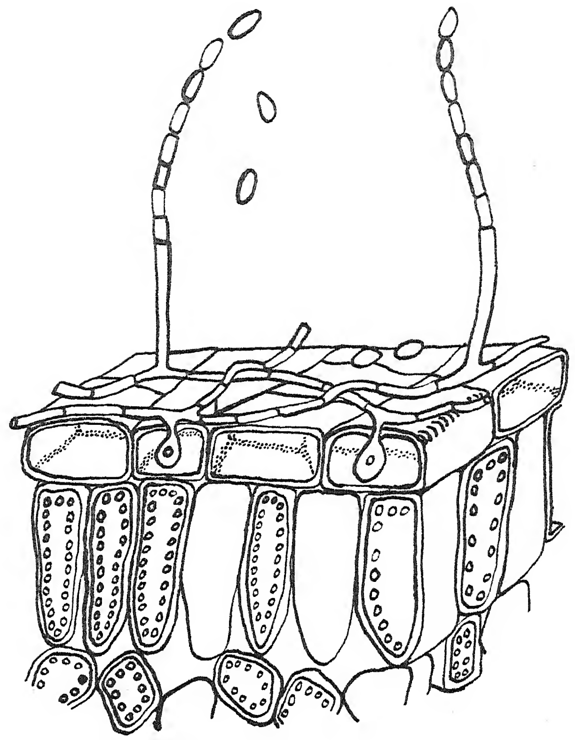
Draw enlarged a mature sporangium as seen in medial longitudinal section.

Draw (1) stages showing progametes and a portion of the mycelium on which they are borne, (2) the division of the progametes to form the gametes, (3) a mature zygote showing its attachment to the mycelium.

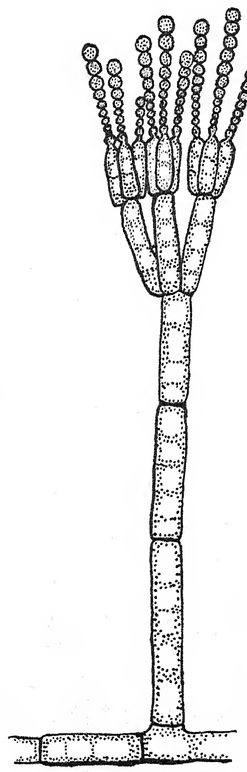
ASPERGILLUS



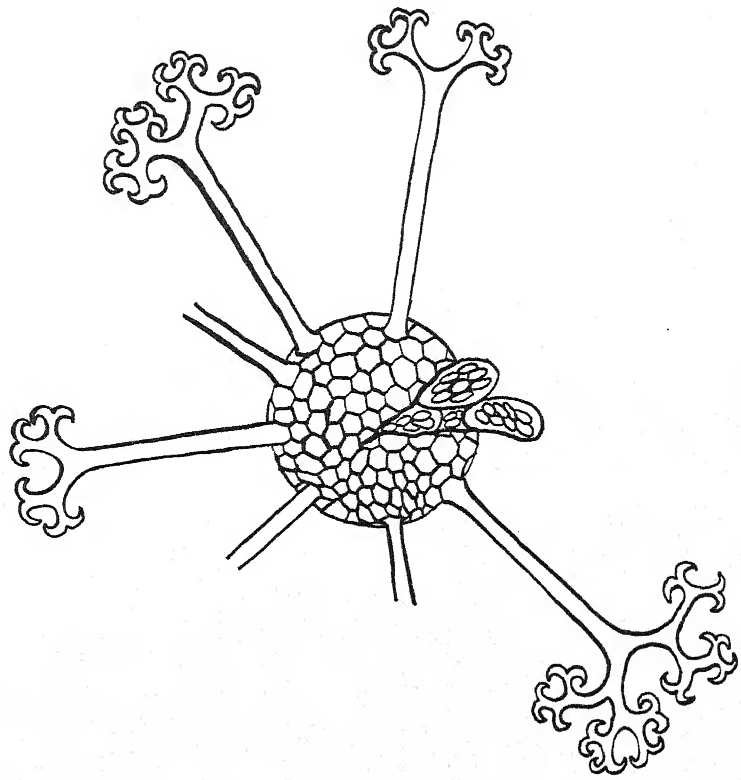
POWDERY MILDEW PRODUCING CONIDIA



PENICILLIUM



PERITHECIUM OF MICROSPHAERA ALNI



ASCOMYCETES

The Ascomycetes are a large group of Fungi characterized by producing spores in sac-like structures, the asci (singular ascus). An ascus is the terminal portion of a hypha usually grown larger and cylindrical though in some cases it develops into globose form. At first there is a single nucleus in the young ascus. By two or three divisions, four, or more often, eight nuclei are produced. These surround themselves with a cell wall to form globose or elliptically-shaped spores. At maturity the spores may be shot out from the tip of the ascus forcibly by virtue of development of unusually high turgor, at least in some species of Ascomycetes. The asci are grouped in specially developed "fruit bodies" in most cases. In the "Cup Fungi" they line the inner surface of the cup-shaped fruit body with an even layer of asci intermingled with which are the terminal parts of hyphae that resemble hyphae but are sterile. These are known as paraphyses. In Peziza these paraphyses are colored a bright red and the total effect of this is to give a bright red appearance to the inner surface of the cup. In the edible Morel (Morchella esculenta) the asci are arranged in the pits of the spongy part of the fruit body. This part is carried on a basal stalk, the whole resembling a mushroom and being prized as a food delicacy.

In the Powdery Mildews the fruit body is small, being usually just visible to the unaided eye, and completely closed. Such a fruit body is known as a perithecium. The asci are irregularly crowded inside this perithecium which grows on the leaves toward the close of the season and falls to the ground with the falling leaves. The ascospores rest over winter inside the perithecium and in spring the structure disintegrates thus freeing the spores. The ascospores start a parasitic growth on the inside of the host leaves where they happen to alight. As the mycelium invades the tissues and draws nutriment from it, the superficial hyphae are greatly developed and form numerous conidiophores. These abstrict conidia in such abundance as to give a powdery appearance to the surface of the leaf, hence the common name. There are numerous species of these powdery mildews infecting such plants as the common lilac, willows and poplars, sun-flowers, nettle, etc. The plant illustrates what is true in many other groups of Ascomycetes, viz., two stages and two types of spores. The first conidial state is sometimes called the "imperfect" stage. The conidia have as their function the rapid wide dissemination of the parasite. Later in the season, after a sexual union of gametes that has degenerated to a rather simple process in most of the plants, the carpophore or fruit body is formed and therein are produced the asci as already described. This may be regarded as the "perfect" stage. It serves not so much to disseminate the parasite as to tide it over the winter season.

In Green Mold (Aspergillus) and Blue Mold (Penicillium) the color of the mold is due to the color of the abundant conidia of the imperfect stage and the perfect stage is either not known or is seldom encountered. Fungi in which the perfect stage is not known at all are classed as "Imperfect Fungi". Many disease-producing fungi of field, orchard and garden crops are "Imperfect Fungi".

The Burnt Fungi (Pyrenomycetes) are a large group of Ascomycetes that form multiple fruit bodies on their substrata or on their host tissues that are at maturity quite black and often give the appearance of burnt areas on the wood or twigs where they occur. This area is covered with little papillate mouths (ostiola) that open from the perithecia sunken into the tissue. Black knot of plum and Nectria are examples.

A large group of saprophytic fungi has degenerated so far as hardly to be recognizable as Ascomycetes. These are the Yeasts that occur in nature where

they cause the fermentation of sugary solutions of ripe fruits, etc. Man has selected some of these species and employs them in fermenting fruit juices to make wines, starches and sugars of grains to make whisky and beer, alcohol, etc. They contain as a rule diastase as well as zymase and are therefore able to change starch to sugar and the sugar to alcohol with carbon dioxide as a by-product. In bread-making the carbon dioxide generated by these plants is responsible for the rising of the bread. The plants have in the course of their degeneracy lost their mycelial character, the cells being in most species solitary. New cells are formed by a mitotic division of the nucleus, but no cross wall cuts the parent cell into two equal daughter cells as we might expect. Instead, a small bud bulges from the side of the parent cell, enlarges so as to receive one of the nuclei and eventually attains the size of the parent cell and breaks away as a new cell. This is known as "budding". When conditions become unfavorable for growth some of the cells are seen to form spores within themselves. These spores, from 3 to 8 in number as a rule, are highly resistant and can tide the plants over difficult periods of time and grow into active plants again when warmth, moisture and starch or sugar return. A cell forming these spores within itself is regarded as a degenerate ascus, hence the classification of the Yeasts with the Ascomycetes.

Lichens are not entirely Ascomycetes but rather a combination into one plant structure of an Ascomycete and an Alga. The interwoven mass of fungus hyphae makes a suitable place for the solitary algal cells to reside and have protection and moisture. In turn the algae manufacture food through their photosynthesis and some of this is taken by the fungus. Such a combination of two plants in which both contribute something to mutual advantage and in which neither can be said to be a parasite on the other is known as "symbiosis". In the animal realm there are also numerous examples of symbiosis such as that of certain species of ants and plant lice.

Lichens are a widely distributed group of plants ranging from the tropics to the farthest north attained by plant life in the Arctic regions. Some grow in wet situations and others are the last outposts of plant life on the edge of the desert. They form foliose membranous growths on bark of trees, fences, old roofs, etc., and some are mere incrustations of rocks. Reindeer moss is an example of a Lichen and on every hand about us are Parmelias, Cladonias, and other species living on the bark of trees. They are usually greyish in color though black forms, bright colored forms, and even gold-colored forms occur. Golden Gate Canyon in Yellowstone National Park is so called because of the abundant golden lichens growing on the rocks of the cliffs.

LABORATORY STUDIES ON ASCOMYCETES

A fruit body of Morel (Morchella) is supplied. It does not show the most important part of the plant as a whole, viz., the abundant mycelium that vegetated in the leaf mold of the forest floor to gather enough food material to form this fruit body. The fruit body consists of a stalk and a convoluted head. Crush a bit of the tissue from the stalk under a cover glass and note that it consists of densely interwoven hyphae rather than of a true parenchyma such as the tissues of higher plants present. Now crush a tiny bit from the surface of the convoluted head and look for cylindrical asci regimented in neat arrangement with paraphyses in between. Try to make out the base of an ascus and note that it is merely the tip of a hypha enlarged and filled with ascospores. Study the cup fungi supplied you and make a microscopic study of a bit of tissue from the inner surface of the cup. Can you find asci and paraphyses? A prepared slide shows these in a smaller species of cup fungi.

Note with hand lens the black dots on the surface of the Lilac leaves supplied you. On which surface or surfaces do they occur? With a drop of alcohol followed by a drop of water, the leaf may be moistened and then the black perithecia are more easily lifted with the edge of your scalpel or razor blade. Mount in a drop of water and look for good mature perithecia with well-formed appendages. Note the pattern of the branching at the ends of the appendages. Is the wall of the perithecium smooth? Color? Now crush the perithecium somewhat by pressing down on the cover glass. It will crack and there will be some of the asci extruded through the crack. Several trials may be necessary before a good picture is obtained. If the perithecium is not quite mature the ascospores inside the asci will not be evident. We cannot well study the conidia in this exercise as they are not well preserved. They are better studied in June or July when they make a powdery surface on the lilac leaf. If you have time to inspect under the microscope the perithecia of Uncinula, another genus of the powdery mildews, you will find quite a different type of appendages attached.

Note general appearance of the blue mold on orange supplied you. This is known as Penicillium italicum. The name of the genus refers to the brush-like compound conidiophores. Note that the margin of an infected area is white and that it gradually goes through a bluing zone into the dark blue of the middle and older part of the area. The white fringe has merely mycelium with young immature conidiophores. As the conidia are formed and mature they develop blue walls. Being produced in such great numbers, they color the whole area blue. Scrape some of the mycelium from the white area and also some from the borderline and mount under cover glass. Note character of the hyphae and look for conidiophores with young conidia attached.

A bit of yeast from a Fleischmann Yeast Cake has been added to the sugar solution in the beaker on your table. Pour some of the solution into the fermentation tube and make it flow into the long arm of the tube until it is full. Then allow it to stand and in the course of the hour, watch for fermentation which can be measured by the amount of carbon dioxide that the tiny plants generate as they are respiring the sugar. Mount some drops of the liquid on a glass slide and look for the plants. Can you find any that are budding or have recently formed buds? On a prepared slide are shown spores of yeast. The spores are highly stained and are easily seen in groups. What is not easily seen in the slide is the wall of the cell inside which they were formed and are held.

Study the specimens of various species of Lichens on display. Find the algal cells held in the hyphae of the symbiotic fungus in the permanent slide of lichen. General shape and character of the algae. Where are the algal cells distributed? Why not all through the fungus tissue?

PLATE XI. Draw fruit body of Morchella and detail of an ascus from the same. Draw perithecium of Lilac Mildew with appendages and detail of an ascus or two as they are seen coming out of a partially crushed perithecium. Detail of a brush-like compound conidiophore of Blue Mold with conidia attached. Several yeast cells enlarged showing budding. One cell with ascospores inside it.

REPORT 4. Symbiosis in Lichens. Indicate nature of the two symbionts, the contribution of each, distribution of the group, character of some of the species, uses to man and in the economy of nature, and methods of reproduction of the plants.

REFERENCES FOR READING

Smith, pp. 328 - 354
Transeau, pp. 541 - 554; 511 - 527
Holman and Robbins, pp. 406 - 435
Emerson, pp. 213 - 222
Robbins and Weier, pp. 336-360
Wilson, Chapter 23

CHAPTER VIII
BASIDIOMYCETES

The highest group of the fungi has as its most universal characteristic the basidium, a club-shaped terminal cell of a hypha that first has a single nucleus which typically divides twice to form four nuclei. Thus far it follows the same plan as the ascus in its development. Instead of these nuclei surrounding themselves with cell walls and becoming spores enclosed within the parent cell wall, we see them moving toward the tip of the basidium where four slender protuberances are developing. These protuberances soon swell at their tips into globose enlargements and then we see a nucleus creeping through the neck of the protuberance into the enlarged part. The enlarged part is the young spore (basidiospore), and the attaching part is known as the sterigma. At maturity, the basidiospore breaks away from the sterigma and is disseminated.

The Basidiomycetes are a large group containing a larger proportion of saprophytes to parasites than is true of the ascomycetes if we except two degenerate subdivisions of Basidiomycetes: the smuts and rusts. Sexuality has been reduced to still lower terms and appears only in the fusing of nuclei in hyphae that are not specialized for this purpose. The fruit bodies are in general larger than those of the Ascomycetes. Such fruit bodies as those of the puffballs, mushrooms, shelf fungi, etc., are popularly known. Barring the Smuts and Rusts, they are less destructive of crops than the Ascomycetes. They are however particularly objectionable in the role of timber decay organisms.

The so-called True Basidiomycetes (all except the Smuts and Rusts) fall into two subdivisions: The Gasteromycetes and the Hymenomycetes. The Gasteromycetes have a fruit body that remains closed when mature while the Hymenomycetes bear their spores on a membrane (hymenium) which is exposed openly at maturity. Familiar examples of Gasteromycetes are the puffballs. The mycelium of these plants vegetates in decaying organic matter for a long time and finally comes to fruition by the production of a globose mass of densely interwoven hyphae. This may at maturity attain large proportions, often more than a foot in diameter in <u>Calvatia maxima</u>, the Giant Puffball. The puffball has two relatively tough membranous outer coats. All the tissue within these produces great numbers of basidia all of which produce four basidiospores each. As they mature the spore walls assume a brown, olive, or black color, and as the whole mass becomes dry, the coats break apart and clouds of basidiospores are carried away by the breezes. So large is the number of these spores as to be almost unthinkable. Very few of them germinate and of those not many succeed in producing new mycelium and fruit bodies.

The attractive little fungi known as Earth Stars (Geasters) are really puffballs, in which the outer of the coats splits open fairly regularly and as it dries opens out, the segments looking like the points of a star. As they bend farther and farther down they finally actually raise the fruit body up from the ground. The spores escape from a little pore in the top of the inner coat so as to give the appearance of a miniature volcano erupting.

The Bird's Nest Fungi are related to the puffballs. In these plants the outer coat opens up widely so as to give the appearance of a bird's nest. Inside are the peridioles, really separate little puffballs, each surrounded by what corresponds to an inner coat. The peridioles may be disseminated unbroken and distribute their basidiospores only as they disintegrate later.

The Buzzard's Nose or Stink-Horn is a related fungus notorious for the foul odor of carrion that it emits when mature. This has a complex structure enclosed within the outer coat which grows upward out of the outer coat into a stalk and a spore-bearing head. Carrion flies and carrion beetles are attracted

to the plant and they carry the spores away, thus effecting dissemination.

The Hymenomycetes consist of Hydnums or "Hedge-Hog Fungi" in which the spore-bearing hymenium is spread over the surface of spines; of Clavarias or "Fairy-Club Fungi" in which the hymenium is spread over the surface of erect branching fruit bodies; of Thelephoraceae in which the hymenium covers a flat surface of tissue. These three groups are not numerous as to species compared to the two other very large groups, the Agarics (mushrooms, etc.) and the Polypores (pore fungi).

The Agarics are the common mushrooms. Popularly, the poisonous ones are spoken of as "toadstools", a name not accepted in botanical literature. These plants constitute an important item of food for the epicure and one is frequently asked how the edible may be distinguished from the poisonous varieties. There is no one single rule. It is necessary to learn to recognize the individual plants by their peculiar characteristics. A good way to begin is to learn to recognize the common field mushroom, the inky caps, the shaggy manes, and then to add gradually other choice edible varieties to the list of those one can make no mistake about. Further it is advisable to learn at once to recognize the very poisonous genus Amanita. It includes the Fly Agaric, the Death Angel, and other deadly species.

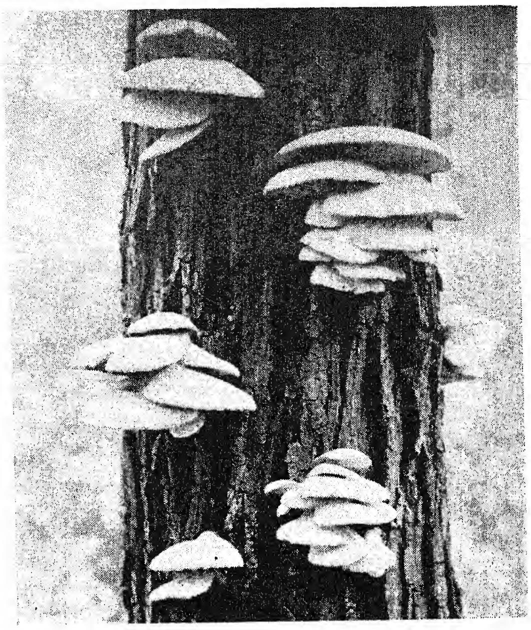
The mycelium of mushrooms lives on dead organic matter in the soil or in the case of some species it vegetates in decaying wood. After a period of growth a concentration of mycelium takes place to make the beginning of a fruit body. At first it is merely a tiny cottony ball of closely interlaced hyphae. This grows rapidly and soon a stalk portion and a cap portion begin to differentiate. The hymenium begins to develop on the folds or gills. In the hymenium the basidia begin forming basidiospores and as they approach maturity the cap opens up in the manner in which one opens an umbrella. On the under side of the cap the radiating gills bear the spores on their surface. The mature spores are white, rose, yellowish, brown, or black. As they fall from the gills the air currents bear them away and disseminate them. The opening out of the cap sometimes leaves some tissue clinging about the stalk in the form of a collar. This is known as the annulus. It is present in some species but not in others so that it may be used for determination of species. The Amanitas, for example, always have the annulus. That together with white spores and a cup-like base from which the stalk arises constitutes the mark of identity for the genus.

The genus Coprinus in which are included the shaggy mane and the inky cap differs from most genera in that the cap does not open at all, but at maturity the gills deliquesce into a black slimy fluid in which the spores are held. This is sweetish to the taste and attracts insects which eat some of the fluid but carry away a part with the included spores and thus secure their dissemination.

Armillaria mellea (the honey agaric) is an example of a mushroom that may grow both parasitically and saprophytically. The mold in the ground may effect entrance to a tree, attacking the living wood as well as the dead. After a time, the fruit bodies appear at the surface of the tree where there is an old wound, or in a knot-hole. When the tree dies, the mushroom continues its growth on the dead wood. In a way, then, we have here a mushroom that causes a plant disease.

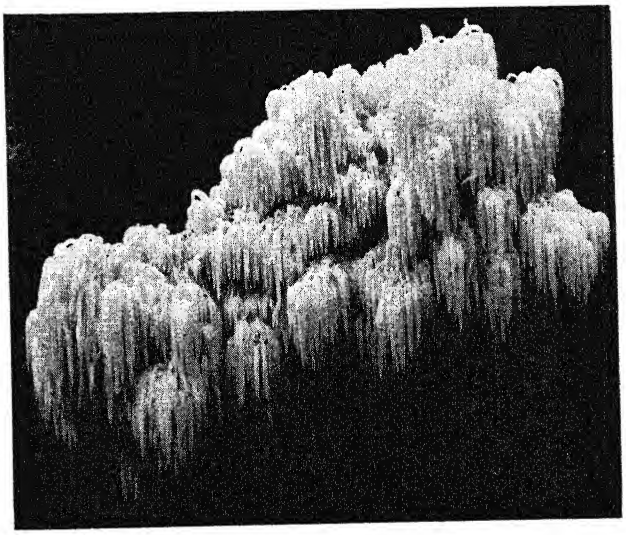
The pore fungi may resemble the agarics in form of the fruit body as is the case in the genus Boletus. These plants look like mushrooms but instead of having gills on the under side of the pileus they have numerous tiny pores just visible to the unaided eye. The inner surface of each pore is lined with the

A SMALL-HEADED SPECIES OF MOREL



OYSTER MUSHROOM ON LARGE-TOOTHED ASPEN

CALVATIA GIANT PUFFBALL



HYDNUM BEAR'S HEAD FUNGUS

A COMMON POLYPORE ON OAK STUMP

COPRINUS INKY CAP

hymenium, and the spores, at maturity, fall down out of the mouth of the pore. Most Polypores are however not centrally stiped but attached at their side to trees or fallen logs. This stipe may be well developed as in the Shiny Polyporus or there may be no stalk at all, the plant being attached broadly all along its base in the form of a shelf, as for example the Artist's Polypore. These polypores are the most active organisms in wood decay and are therefore useful in the economy of nature in reducing the dead fallen trees to the elemental substances from which they were formed. On the other hand they are annoying to man in his scheme of things as they cause the decay of his timber and lumber, and they limit the life of his wooden houses, cross ties of railways, posts, etc.

LABORATORY STUDIES OF BASIDIOMYCETES

Study the puffball supplied you. Note mycelium at point of attachment to decaying wood. The mycelium was extensive, reaching all through the wood of the stump on which the fruiting body was found. Cut across the fruit body. Note two outer coats, the outer and inner peridia. Within, there is a mass of interwoven hyphae with small labyrinthine chambers all through it. The basidia are arranged in a layer lining these chambers. When mature, the whole mass blackens because the spore walls are black. See the slide of Lycoperdon, a puffball, on your table. The labyrinthine chambers are clearly seen and also the inner and outer peridia. The basidiospores and not yet formed at this early stage.

The common field mushroom, Agaricus campestris, is the most prized for food. It is collected in pastures by mycophagists and is cultivated in cellars, abandoned coal mines, sand caves, and similar situations. Note the characteristics of the plants supplied you. The stalk or "stipe" is rather thick and bulbous at base. Some of the mycelium may still be attached at the base. A ring or annulus surrounds the stipe below the cap or pileus. The pileus is smooth on its upper surface. The upper surface is sharply convex when young but flattens out more as it grows older and may actually be quite concave in very old specimens. On the under side are the radiating gills. Note how admirably they are adapted to the increase of surface for the hymenium. They are white when young. As they mature they turn pink and finally black. This color change is due to the development of color in the walls of the spores.

A permanent slide shows cross sections of the gills. Note the inner stroma, the hymenium, the paraphyses and basidia, the sterigmata on the basidia and on these the basidiospores.

Coprinus includes the inky caps and shaggy manes. They never open their pileus. A slide on your table shows cross sections of the entire pileus of a very tiny species of Coprinus. Note that the unopened pileus gives in cross section the appearance of a wheel, the spokes being the gills. The spores are mature—and by careful observation you will find the sterigmata of the basidia, some of them still having their spores attached, though most of the spores you see were detached in the process of manipulating the tissue for making of the section.

Note character of the fruit body of the Artist's Fungus on the table as an example of a polypore. With hand lens inspect the mouths of the pores and where the section is cut across you can ascertain the great depth of the pores. This species often continues its growth a second, third and even fourth year, forming each season a new pore layer. The stroma of the fruit body is quite woody and

illustrates how firm a tissue may be formed by a pseudoparenchyma. Study prepared slide of pores of a polypore.

Study display specimens of the various Basidiomycetes on demonstration table. Also charts on the wall depicting species of agarics.

PLATE XII. Make quick habit sketches of (1) a mushroom, (2) a polypore, (3) a Clavaria, (4) a Hydnum, (5) a puffball, (6) an earthstar, (7) a bird's nest fungus.

Draw a cross section of a single gill of a mushroom much enlarged and a portion of the hymenium still more enlarged to show paraphyses and basidia with sterigmata and basidiospores.

THE SMUT FUNGI

This group of degenerate parasitic Basidiomycetes accounts for heavy annual losses in our grain crops. The mycelium grows in the vegetative tissues of the corn stalk, wheat plant, or other cereal plant and does not do much apparent harm. When the grains begin to form, however, the mycelium concentrates its forces at the fruiting head and the abundant food supply rushed to the grains by the host plant are seized upon by the fungus to be converted into mycelium and later into spores. When the grain should be mature, you have no grain at all but just a black mass of spores (smut). These spores germinate in the soil or decaying organic material, sending out short germ tubes which are really the homologues of basidia. They form short sterigmata at the ends of which are produced basidiospores (here usually called "sporidia"). These are blown to the living cereal plants and start the life cycle all over again.

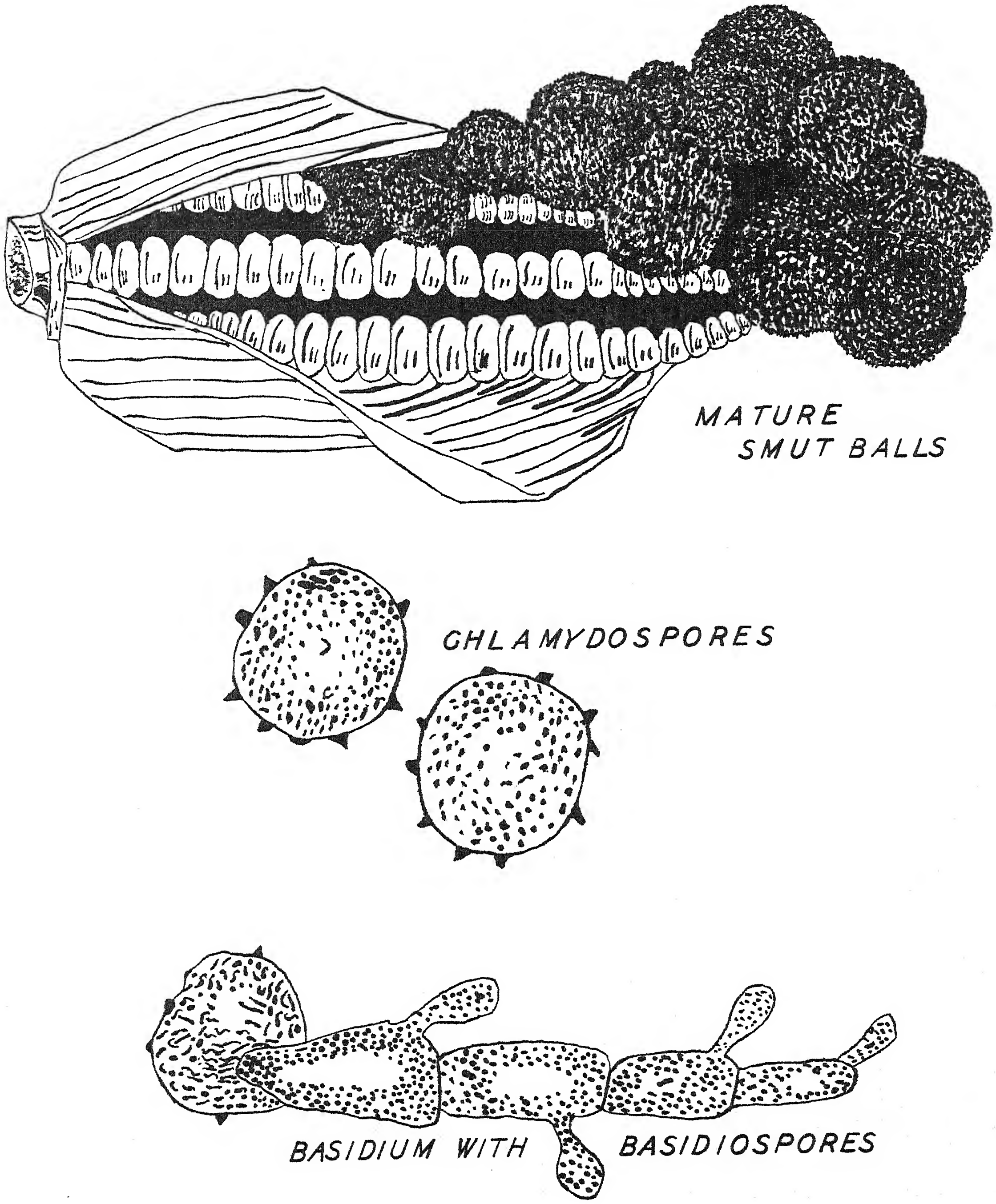
Three types of host infection occur in the various species of smut plants: (1) Seedling infection, in which the spores cling to the host seeds and when they are sown and germinate, the spores also germinate and grow into the seedling. All oats smuts are examples, also stinking smut of wheat and covered smut of barley. (2) Flower infection, in which the spores can infect only the flower, growing into the ovary and developing to some extent in the embryo of the seed. During the dormancy of the host seed, the mycelium also rests and when the seeds are sown, the mycelium starts and keeps pace with the developing host plant. Loose smuts of wheat and barley are examples. (3) General infection, in which the sporidia may gain entrance into the plant at any part, particularly young growing parts of the plant. Corn smut is an example. The corn stalk is subject to infection at any time and particularly at the nodes where the tissue is perpetually meristemmatic.

The smuts annually destroy millions of bushels of our cereal grains. Those species which infect the seedling host plants can be combatted by destroying the spores on the host seeds before sowing. Formaldehyde gas and hot water are used for this purpose. Sanitation, destruction of spore masses, rotation of crops, selection of seeds from fields free from smuts are other measures employed.

THE RUST FUNGUS

Rusts as causes of plant diseases were known from times prehistoric. In fact the Romans had a rust god, "Rubigus", and they celebrated annually the Rubigalia in an effort to appease Rubigus and persuade him to go easy on their crops that year. As part of this effort to appease his rusty divinity, a

CORN SMUT


MATURE
SMUT BALLS
CHLAMYDOSPORES
BASIDIUM WITH BASIDIOSPORES

sacrificial dog was offered on the altar. The dog was selected with a view to getting his fur to resemble mature rust as nearly as possible. Today the technique of combatting rust is somewhat different. Instead of a rusty-colored dog, we sacrifice our choice ornamental Common Barberry bushes, as science has established the fact that the rust of wheat and other cereals is complicated in its life history and that it must alternate between hosts, spending part of its life history on the leaves of the Barberry and part on the cereal plant. To save the cereal plant, one has only to deprive the fungus of an opportunity to grow on the Barberry.

In Wheat Rust there are five spore forms:

1. Uredospores, the red rust spores of the wheat. They may infect other wheat plants.
2. Teleutospores, the black rust spores of the wheat that come from the same mycelium as the red rust but appear toward the end of the season. They are two-celled and have a very thick wall. They rest through the winter and with the warm spring rains they germinate by sending out from each cell a tubular growth which is really a basidium though it does not resemble the typical basidium of Agarics, etc. On this basidial growth appear sterigmata and on these are formed the
3. Basidiospores. The basidiospores are blown to the leaves of the barberry bushes which they infect.
4. Pycniospores result from the mycelium that developes in the tissues of the Barberry leaf. They are borne on the upper surface of the leaf in special structures known as pycnidia. They are necessary to the life history of the plant, as they supply the male element in sexual fusion.
5. Aecidiospores are formed from the same mycelium but in different type of cluster cups on the lower surface of the barberry leaf. They are blown to the young wheat plants where they start the red rust stage.

Not only are the cereals subject to rusts but almost every plant has a rust parasite and some plants have many species. The White Pine Blister Rust threatens the extinction of our White Pines. Broadleaf trees, shrubs, ferns, annual and perennial seed plants, all are menaced by the rusts which run into thousands of species. The rust parasites do not kill their hosts but they weaken them and turn food material to their own use that should go to the development of new growth and particularly to fruit and seed formation in the host plant.

LABORATORY STUDIES OF SMUTS AND RUSTS

When the spore masses of corn smut are young they are white throughout and are used as food by some mycophagists. As they mature the mycelium is changed into a mass of chlamydospores. These can be seen easily by crushing a bit of the spore ball under cover glass and examining microscopically. Similarly study the spores of oats smut. Study permanent slides of smut tissue.

Study leaves of Common Barberry infected with <u>Puccinia graminis</u> (wheat rust). Compare these leaves to those of Japanese Barberry which is immune. Can you find pycnidia on the upper surface of the leaf with your hand lens? On lower surface study under hand lens the clusters of aecidia inside of which the granular spores are seen. The permanent slide shows sections through the aecidia. The cup is surrounded by a wall tissue known as the periderm. The spores within arise from basal hyphae which resemble conidiophores but are not homologous with them. The spores are formed in succession so that as the outer ones are blown away new ones continue to be pushed up. Note the neat arrangement of the spores in the cup in definite series. Can you trace the mycelium of the parasite in the host tissue in the area beneath the cup?

On wheat stems study with hand lens and view under demonstration binocular the pustules of red rust and those of black rust. Permanent slides of both are also supplied. Note that the spores form under the host epidermis and as the epidermis dries and breaks they become free to escape to the outside air. Note the two-celled character and the very thick walls of the teleutospores.

Study life cycle of this rust on the wall chart. Inspect the government literature on your table relating to this parasite.

See demonstration of the Cedar-Apple rust. This alternates between the red cedar tree and the apple tree.

PLATE XIII. Draw smut ball of corn supplied you in sketchy outline. Much enlarged, several of the spores (chlamydospores) showing the character of the wall. Sketch panicle of healthy oats and beside it a head of smutted oats.

PLATE XIV. Draw x 2 a Barberry leaf, under surface, showing the sori (clusters) of aecidia. Detail of median section through an aecidium as seen on permanent cross section slides of Barberry leaf. Draw x 2 a bit of wheat stem showing a pustule of red rust. Similarly, a bit of stem showing pustule of black rust. Much enlarged detail of uredospore and of teleutospore.

REPORT 5. Write the life history of the White Pine Blister Rust.

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CHAPTER IX

LIVERWORTS AND MOSSES

Thus far we have been studying the Thallophytes, a very large group of primitive plants falling into subdivisions, the Algae and Fungi. The Fungi descended from the Algae because of their dependent saprophytic and parasitic habits. Now we shall have a look at another group of plants derived from the Algae, but instead of degenerating, this group ascended and assumed more of the characteristics of the higher plants. We find in the tissues of the Liverworts and Mosses true parenchyma like that found in the Seed Plants. No longer are the solid structures made by the dense interweaving of hyphae, but the cells form a solid three-dimensional solid tissue. Similarly, the plants of this group have become more terrestrial in habit and have developed root-like, stem-like and leaf-like organs, though we cannot call these organs true roots, stems, and leaves because they lack conducting tissues. Because of the lack of conducting tissues, these plants do not attain a large size. As soon as they reach a distance of twelve inches or thereabouts from the soil where is their source of water, their tissues stand in danger of drying out.

Alternation of generations becomes more pronounced in this group and the two generations are more of an equal importance than was the case in the Thallophytes which show a pronounced X - generation or gametophyte and only an insignificant 2X-generation or sporophyte. Along with this increase in the importance of the sporophyte generation we see the change from an oogonium to an archegonium. The archegonium of these liverworts and mosses (jointly called "Bryophytes") differs from the oogonium in having cellular walls surrounding the egg cell and a cellular neck-line part for the reception of sperm cells. The antheridium of the bryophytes likewise differs from that of the Thallophytes in being possessed of cellular walls.

The Bryophytes as a whole are not a relatively large group but they are widely distributed over the surface of the earth. Relatively few species are aquatic. They reach far into the cold Arctic country and high above the snow line of mountainous regions. At the same time there are many tropical species. From the point of economic importance to man the Bryophytes are well nigh negligible. They are not used for food or other necessities, but on the other hand they also do not offend by causing plant diseases or making themselves otherwise undesirable.

We can trace in the Bryophytes the evolution of the sporophyte from a relatively simple structure to a highly complex one. As an example of a plant with simple sporophyte we may consider Riccia, a simple liverwort that has both aquatic and land forms. The aquatic forms grow in the form of slender dichotomously branched ribbons. The land forms are much shorter and thicker but still exhibit the dichotomous branching. The land form has abundant rhizoids, root-like hairs, that grow on the under surface and anchor the plant to the ground. On the upper surface the thallus has a mid-rib-like depression running the length of the thallus. In the bottom of this depression are the sex-organs. The whole structure grows in length by an apical cell at the youngest tip. When the apical cell divides laterally into two apical cells each of these proceeds to produce a branch, which gives rise to the dichotomous branching.

The sex organs consist of erect antheridia attached by a cellular stalk below and having a globose shape, the walls consisting of a single layer of cells. Within, there are produced numerous 2-ciliate sperm cells which escape from the tip of the antheridium at maturity and swim in the film of rain water or dew that may be on the plant. The archegonium likewise has a cellular wall.

An enlarged part at the base is known as the venter. It contains within itself the large egg cell. Projecting upward from the venter is the neck. Inside the neck is a row of small cells which deliquesce into a mass of mucilage as the archegonium matures. This makes a mucilaginous canal from the tip of the neck down to the egg cell. The sperm cells swim to the entrance of this canal, attracted by chemical secretions, and then make their way through the mucilage and down to the egg cell. One sperm fuses with the egg cell, thus making a 2X nucleus. The fertilized egg now begins dividing and makes a large mass of cells. The archegonial wall also grows to keep pace with the enlarging structure, the young sporophyte, inside. When the sporophyte has attained mature size its cells begin differentiation. All those in the outside layer form the wall of the sporophyte. All others inside become spore-mother-cells. Each spore-mother-cell divides twice to form four spores. In one of these divisions the number of chromosomes is reduced from the 2X to the X number. The spores are therefore the first cells of the next gametophyte generation. The four spores resulting from a mother cell cling together for some time and are known as a tetrad.

When the portion of the thallus in which the sporophyte has formed becomes old and dies, its tissues disintegrate and the spores of the sporophyte are set free to grow into new gametophytes. Thus we see that the sporophyte is quite dependent on the gametophyte generation for food supply and protection. On the other hand the gametophyte generation can start only from a spore produced by the sporophyte generation. The alternating of gametophyte with sporophyte is known as "Alternation of Generations."

Marchantia is a much more aristocratic liverwort. Its gametophyte thallus has little diamond-shaped rooms all over the upper surface of the thallus. In each of these chambers are specialized chlorophyll cells. At the top of each chamber a pore opens to the outside to allow exchange of gases. The pore is walled about with cells in the manner of a chimney. The sex organs are lifted aloft well above the flat prostrate thallus by means of erect branches an inch or two high. The female plants have these erect branches bearing horizontal branches in a radiating group at their tip. The whole structure is known as an archegoniophore since it bears archegonia below and between the terminal horizontal branches. The archegonia are constructed like those described for Riccia. They grow with their necks downward, however. The sperm cells must swim up the sides of the archegoniophores through a film of water in order to reach the archegonia. The antheridia are borne on different male plants in a similar situation except that the antheridiophore is not so distinctly branched at the top, the branches being mere scallops in the side of a terminal disc. The antheridia are in the top of this disc, the necks coming to the mouths of the depressions in which the antheridia are sunk. The sperm cells are 2-ciliate and resemble those of Riccia.

After fertilization, the egg cell begins to develop into the sporophyte, which in Marchantia is a more specialized structure than the simple globose sporophyte of Riccia. It develops a sterile basal part, the foot, which keeps it anchored in the gametophyte tissue. Its sporangium has a sterile wall of cells. When the sporogenous tissue develops into spore-mother-cells, not all of it goes to form spores. Some of the cells develop into long hygroscopic threads known as the elaters. They become fluffy and loosen the mass of spores at maturity when the weather is dry, but tighten up in damp or wet weather. This keeps the spores in the sporangium in weather unfavorable for their distribution, but allows them to escape at other times. It will be seen then that less of the sporophyte develops into spores and more is sterile than was the case in Riccia. This "progressive sterilization of sporogenous tissue" is characteristic of the evolution of the sporophyte in general.

The "Leafy Liverworts" have their thallus not ribbon-like and flat but there is a central axis to which are attached leaf-like lobes. They are common on rotten logs and the bark of trees. They resemble the mosses more than the liverworts of the Marchantia type. Their capsules are borne on stalks and resemble superficially those of the moss but are very simply constructed within.

The "Horned Liverworts" have their sporophytes in the form of long cylindrical outgrowths from the flat thallus of the gametophyte. Between the central sterile columella that runs the length of this sporophyte and the thick sterile outer wall there is developed the sporogenous tissue. It matures into spores first at the tip and then continues to mature gradually as the sporophyte grows in length. The spores are then progressively produced so that there are always some ripe spores ready for dissemination. The cylindrical sporophyte is usually somewhat curved so as to give the impression of a horn, hence the common name. This horn splits lengthwise into four segments as the spores mature and continues to split downward so as to liberate the spores when they mature. In many respects this sporophyte is the highest attained in the liverworts and resembles that of the moss plants to be next studied.

There are two types of mosses: the "true mosses" and the "peat or bog mosses." The latter are technically called Sphagnum. The true mosses are gregarious, forming cushions of green on damp soil and on decaying logs, tree trunks, etc. The plants start from spores which first grow into a green alga-like mass of filaments known as the protonema. On this protonema there develop buds from which leafy shoots grow upward. This is all a part of the gametophyte generation. The mass of leafy shoots is what the average person knows as moss. The central stem-like organ has no conducting tissue but the cells in the center are much elongated so that the water does not have to pass through so many cross-walls in its osmotic movement upward. These elongated cells may be regarded as the forerunners of tracheids. The leaf-like organs have thickened mid-ribs but the lamina are usually one or two cells thick. There is of course no epidermis with stomata. Nor are there palisade cells, spongy mesophyll, and the other structures that you know in the higher leaves.

At the tip of the leafy shoot the archegonia and antheridia develop. They are usually surrounded by a rosette of leaves. Scattered among the sex organs are characteristically shaped paraphyses. In some mosses the two kinds of sex organs are on the same plant (monoecous), in others the two are separate (dioecous). The archegonia are similar to those of the liverworts but usually more slender and elongated. The antheridia are sac-like. The sperm cells are 2-ciliate.

After fertilization, the egg cell develops rapidly into a long slender stalk-like structure that grows to a height of a fraction of an inch to two inches, depending on the species, and then begins to develop a very highly specialized capsule at its extremity. The capsule has at its top a cap-like structure that often looks like a candle snuffer, a fools cap, or a thatched hut. This is the calyptra and is not truly a part of the sporophyte since it represents the structure which has developed from the continued growth of the upper part of the venter and the neck of the archegonium. The capsule proper is however covered by a sugar-bowl lid-like structure, the operculum. Not all of the interior of the capsule turns into spores. There is a large columella. The wall is highly organized and contains much chlorenchyma. Between the columella and the thick wall is a rather small amount of sporogenous tissue in the form of a hollow cylinder. At its top it is covered not only by the operculum but also by a row or two rows of teeth, the peristome. These teeth shut down over the sporogenous

area firmly so long as they are damp. At maturity of the capsule, when the teeth become dry they gradually open upward and the spores can sift out and become disseminated by the air air currents. Should a rain or the dampness of night come, they close down again and protect the spores until more dry favorable weather returns.

Of significance to the student of the evolution of plants is the high development of the sporophyte in the mosses. The seta as well as the walls of the capsule contains chlorenchyma and is therefore able to contribute to its own support. It never becomes entirely independent of the gametophyte however. In the Pteridophytes we shall see that complete independence has been attained for at least the greater part of the life of the sporophyte.

Sphagnum moss differs from the true moss in some respects so that it is not classed with them. It has a highly specialized gametophyte that is adapted to the acid peat bog conditions in which it is generally found. The leaves have special dead water reservoir cells so that it can resist drying for a long time before losing all the water from these reservoirs. Its great absorptive power has made it of use as bandage material. It is used in the soil as a moisture retainer. Further it serves to acidify the soil, since it carries the acid condition of the bog in which it grew with it. Pure stands of great extent are found in bogs all across our continent in the northern part. In Ireland and on continental Europe there are likewise extensive peat bogs. The acid condition makes the bogs antiseptic and moss does therefore not decay but becomes gradually carbonized and eventually makes the fuel known as peat.

The sporophyte of Sphagnum is much simpler than that of the true mosses. It does not even possess a stalk of its own but is borne aloft by a stalk-like outgrowth of the gametophyte. The columella does not extend completely through the capsule but is merely a dome-shaped elevation from its bottom.

LABORATORY STUDIES OF LIVERWORTS AND MOSSES

Riccia is one of the simpler forms of liverworts. The land form of the species before you in the watch glass is short and compact while the aquatic form grows more attenuated. In organization of the thallus the two forms are really quite similar; both consist of a ribbon-like thallus that branches dichotomously; both have root-like rhizoids on their under side (very few in water form); both have a notch at the apex of each branch, in which is the embryonic tissue constituting the growing point; both have a mid-rib-like furrow running along the middle of each branch.

Slides show cross sections of the thallus with sex organs in the mid-dorsal groove. Note that the antheridia here are different from any we have seen in the algae in that they have a cellular wall. The same is true of the archegonia. Note venter, egg cell, neck, and neck canal of the archegonium.

The fertilized egg cell develops into a globose sporophyte that appears black when mature. Dissect out one of the sporophytes and note under magnification that it has a single layer of cells in the wall and that the entire content consists of spores. Character of the walls of the spores. Do they adhere in tetrads?

Study the thallus of Marchantia. Note with hand lens and under demonstration binocular the diamond-shaped areas on the upper surface, each one having a pore in the center. Note growing point, midrib, rhizoids, dichotomous branching.

Cross section of thallus in slide supplied you shows structure of the upper epidermis with its pores, the limiting side wall of each diamond-shaped air chamber, the chlorenchyma cells at the bottom of the chamber, and the lower non-chlorophyllous tissue of the thallus. Do you find any special markings on the rhizoids on the under surface of the thallus?

Asexual reproduction is brought about by the gemmae (buds) that grow in the gemmae cups. When a gemma falls upon the soil, it sends out rhizoids and proceeds to develop into a thallus.

The antheridia are embedded in the upper surface of the enlarged top of the antheridiophore. A minute pore opens from the depressed chamber in which the antheridium is situated. The slide supplied you illustrates these. Most of the antheridia in these slides are devoid of their sperm cells but the younger ones near the margin still retain them. The archegonia are not embedded but are borne on the under side of the tops of the archegoniophores between the digitate divisions. They are surrounded by protecting scales and rhizoids. See slide cut through the top of an archegoniophore and look for archegonia. Not all are cut through the egg cell and throughout the length of the neck.

Sporophytes appear later in the season, developing from the fertilized egg cell. A sporophyte has a foot, stalk, and capsule. In the capsule you find the spores and the elaters. What is the structure of the elaters? Dissect out a preserved sporophyte. Study the slide showing section of sporophyte.

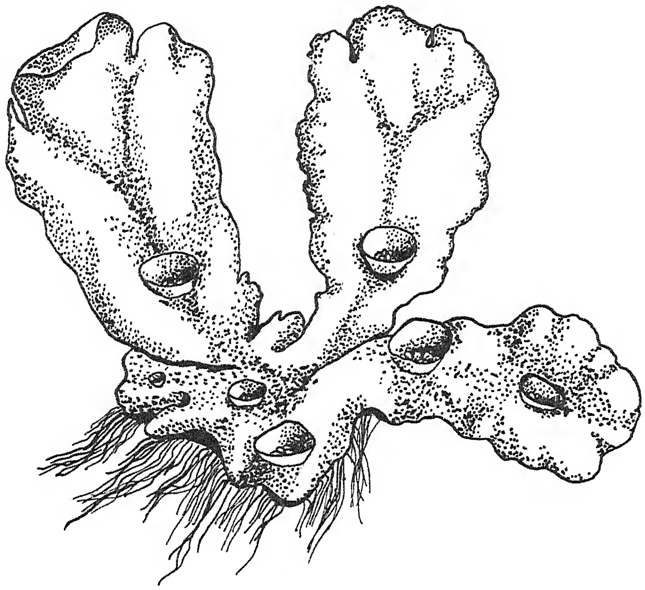
PLATE XV. Draw sporphyte of Riccia. Much enlarged, an antheridium and an archegonium. Label the drawings of Marchantia on the accompanying page. Median longitudinal section of a sporophyte.

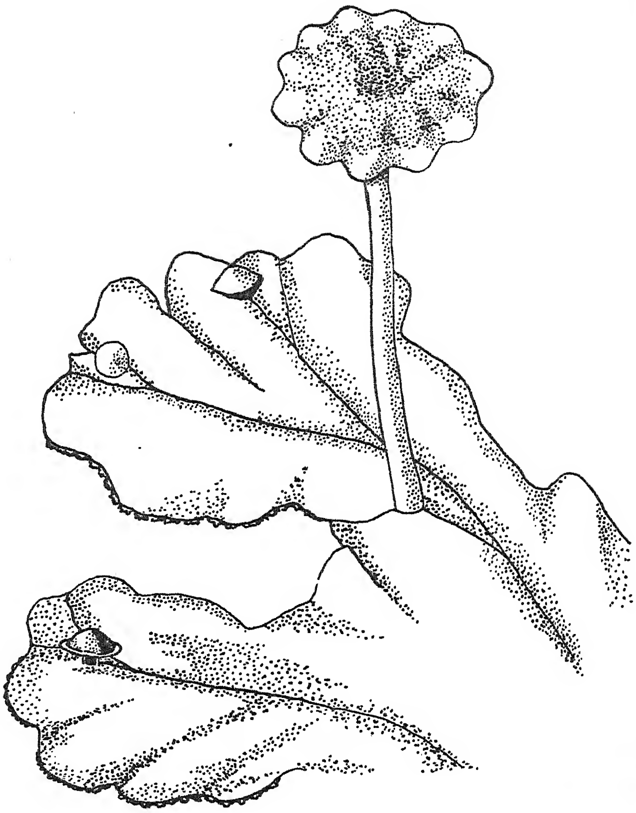
TRUE MOSSES: In the mosses the spore upon germination first produces a branching filamentous growth resembling green algae. It is known as the protonema. It is well shown in the permanent slide supplied. Do the filaments branch? Do you notice any oblique cross walls? Is chlorophyll present in any or all of the filaments? Bulbils may also be found. Note the character of the cross walls in these. Look for buds or young leafy shoots.

The mature leafy gametophyte develops from buds that form on the protonema. Several young leafy shoots are shown in each slide.

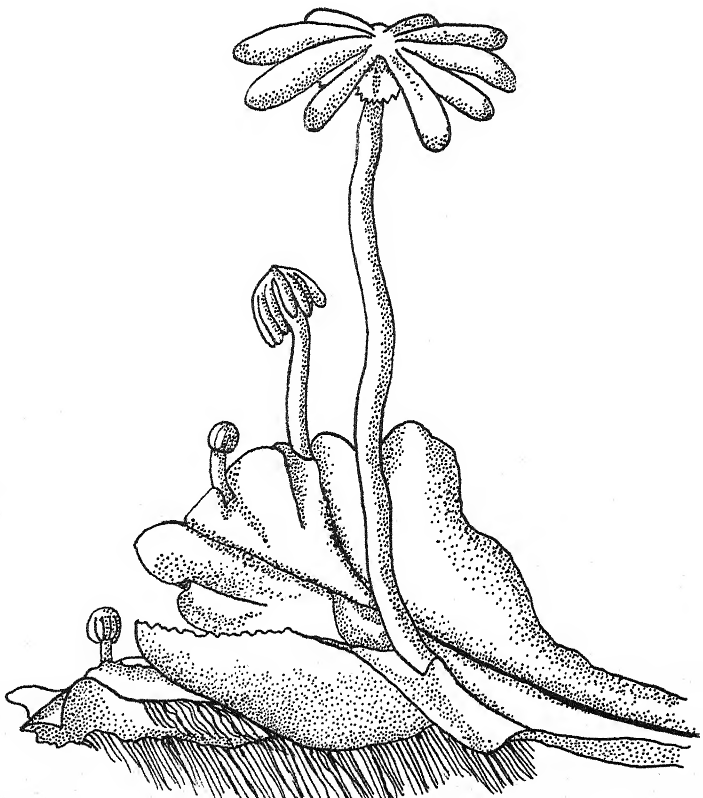
In the tips of the leafy shoots the antheridia and archegonia are found. Two kinds of leafy shoots (labeled male and female) from a dioecous moss are supplied you. With a pair of forceps pull away the leaves one by one that surround the tip of the shoot. Then cut away about a millimeter length of the tip. Place this in a drop of water on the slide and with a pair of needles dissect it apart. Cover and examine to find the sex organs and the characteristic paraphyses.

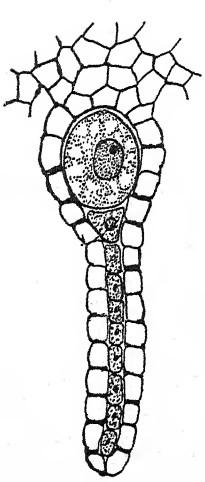
When the egg has been fertilized it grows into the sporophyte. Study the sporophyte of Pigeon Wheat moss supplied you. The dry specimens show the hairy calyptra which gives the other common name of hairy-cap moss. Does it consist of gametophyte or sporophyte tissue? Under the hairy cap note the operculum. As it is removed the peristome teeth come into view. Split the capsule and lay it out so that you may see the peristome. Determine the number of teeth. Study the nature of the spores. In the longitudinal section of a capsule note the extensive tissue in columella and wall and the relatively small amount of sporogenous tissue.

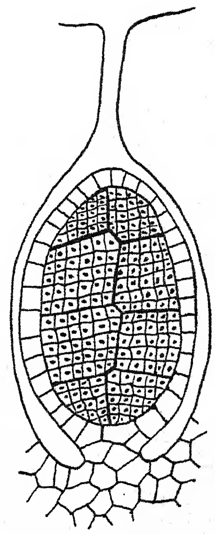




Gage







SPHAGNUM: Note the finely branched character of the shoots. Remove several single leaves and under magnification find the two kinds of cells in the leaf. What is the function of each kind?

Note the sporophytes in the tip of the shoot or near the tip. What color are they? How do they differ structurally from the sporophyte of true moss? How does the seta differ? Note the demonstration slide of a section through a capsule.

PLATE XVI. Draw protonema, bulbils and young leafy shoot. Draw an antheridium and an archegonium together with their paraphyses. Draw the sporophyte of Pigeon Wheat with calyptra and beside it the same without calyptra. Draw a portion of the peristome.

Draw a bit of Sphagnum leaf to show character of the cells.

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Transeau, pp. 638 - 654
Weatherwax, pp. 292 - 301
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Holman and Robbins, pp. 463 - 496
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Wilson, Chapter 25. A good summary of Liverworts and Mosses.

CHAPTER X

FERNS

The third large group of plants, the Pteriodophytes, consists of Ferns and Fern Allies. The Ferns are an ancient race, being abundantly represented in fossil remains, mostly in the form of leaf impressions in shales and coal of the Carboniferous Age. It has been recently discovered that some of the frond impressions that resemble so strikingly our modern ferns were really those of plants more advanced in the scale of evolution than our modern ferns. It was discovered that they produced not just spores as do our ferns but that they produced a primitive type of seed not unlike the seeds of Cycads and Maiden Hair Trees, which are our most primitive seed plants in existence today. This class of plants, now all extinct, was named Pteridosperms, indicating that they combined characteristics of Pteridophytes and Seed Plants. The true ferns and the Pteridosperms probably existed side by side, both having come from earlier common ancestors. The true ferns persisted to the present time while all the Pteridosperms became extinct.

The Ferns point to a relationship with the Bryophytes, particularly in the structure of their gametophytes and accompanying sex organs. The simple small gametophyte, often called a prothallium, of a fern has much in common with liverworts and mosses. They all have ciliated sperm cells and are therefore dependent on water for fertilization. The structure of the archegonia and antheridia is quite similar in the two groups. The greatest difference appears in the great advance that the sporophyte of ferns has made, the sporophyte having made a great stride ahead to make it resemble the seed plants that descended from the ferns or probably from the Seed Ferns (Pteridosperms). This advance to true roots, stems, and leaves was made possible by the development of conducting tissues and fibrovascular bundles similar to those of seed plants and entirely unknown in the Bryophytes. The possibility of conducting water from the roots to remote portions of the plant made possible tree-like proportions to these plants such as we see in the tree ferns of our modern tropical forests.

The common fern plants that we know in the shady ravines of our woodlands and those that we cultivate in our conservatories and window boxes are the sporophyte generation of the plant, the gametophyte generation being insignificant and popularly unknown. The stem of the sporophyte is in most species horizontal, growing below the surface of the ground or leaf mold and sending up only the clusters of fronds or leaves. Such an underground stem is known as a rhizome. It branches occasionally and grows by an apical growing point. Each year an inch or more of new growth is added. From near the tip of this new growth the fronds arise in the spring of the following year. After some years the old parts of the rhizome die and when decay has taken place to a branching point, two rhizomes entirely separate result. In this way the plant spreads through the forest floor and multiples vegetatively. The rhizome is covered with brown scales that originally protectively covered the growing point. The roots arising all along the rhizome are of the fibrous type.

The leaves, popularly called fronds, are in most of our ferns deeply dissected, though in the walking fern they are entire and in many of the tropical ferns the leaves are not at all indented or cut. The fern leaf is rolled inward circinately when young and as it unfolds it presents a figure popularly called a "fiddle-head" or "monkey-tail." The mature leaf has a stalk or stipe which continues into the lamina part of the rachis. From the rachis arise the pinnae. The pinnae may be subdivided into pinnules.

On the pinnae or pinnules of such ferns as the common polypody are formed groups of sporangia known as sori. The sorus may be covered by an umbrella-like

protective structure known as an indusium or it may be openly exposed. The sporangia are small, being just visible singly. Each sporangium has an attaching stalk and a capsule. The capsule is covered with a single layer of wall cells except for a ridge running about two-thirds around it which has heavy wall cells that are highly hygroscopic. In maturity, this ridge of cells, known as the annulus, straightens out when the sporangium dries and in doing so it tears the sporangium open, usually along definite lines of breakage in the cells. It straightens and even bends back carrying up the most of the mass of spores from inside. Suddenly it reaches the breaking point of the surface tension in the individual cells and snaps shut. This sudden motion throws the spores outward in the manner of a catapult.

The spores have two coats, the intine and the exine, the latter being the hard outer coat, usually brown in color. When the spore alights on the moist soil it takes in water and swells so as to crack the exine. The intine, being a thin membranous coat now bulges out through the crack and as the protoplasm grows, the protruding part grows into a filamentous alga-like structure which however soon begins to broaden out by the division of the tip cells at right angles to the direction of the earlier divisions. A single cell in the tip becomes the apical cell and from it all new cells are originally cut off, but the resulting cells may later divide again. The growth resulting resembles the thallus of a liverwort. It is usually more or less heartshaped, the point of the heart being the oldest part and the sinus having the growing point. On the under side are found thread-like rhizoids which anchor the prothallium to the ground. Scales are also formed just below the growing point and these later persist along the under surface especially along the mid-ventral line.

Antheridia and archegonia are developed on the under side of the prothallium, the antheridia occurring back nearer the old part of the thallus while the archegonia are just back of the sinus. In small poor prothallia resulting from poor soil conditions or from too crowded conditions only antheridia are produced. It requires larger well-fed prothallia to form archegonia.

The archegonia are not much different from those encountered in the liverworts. The venter is usually completely sunken into the tissue of the prothallium and the neck curves back somewhat. The antheridia have a simple wall formed of few cells according to a definite pattern. The sperm cells are elongated coiled structures with numerous cilia. At maturity they swim through the film of water covering the prothallium and are attracted to the mouth of the archegonium by the secretion of malic acid from its neck canal. They swim down the mucilaginous neck canal and reach the egg cell in the venter. After fertilization the egg cell immediately begins growth to form the 2X sporophyte generation.

The first two divisions of the fertilized egg divide it into four quadrants, each of which is destined to develop a definite tissue. The two upper quadrants develop into foot and stem, the two lower into primary root and primary leaf. The foot is the organ that retains attachment to the prothallium and secures food therefrom until the primary leaf is large enough to manufacture food independently. The primary leaf emerges through the sinus and as it grows the sporophyte gradually becomes independent of the gametophyte, a thing that never happened in the whole life history of the liverworts and mosses. We see in the ferns then a great stride in the direction of increased importance of the sporophyte and diminished importance of the gametophyte. This we shall see is carried still farther in the Fern Allies and in the Seed Plants.

LABORATORY STUDIES OF FERNS

Prothallia are supplied of the common ostrich fern, both preserved and in whole-mounts on permanent slides. Study character of antheridia, archegonia, rhizoids, growing point. In stained slides the sperm cells can usually be seen in the antheridia. In the sectioned slides of prothallium, the archegonia in various stages of development are found. They are developed from the sub-epidermal layer of tissue. A complete mature one with egg in place and the full length of the neck showing is hard to prepare in such a section as this. It usually is necessary to piece together parts from two or three sections in order to get the complete picture. The egg cell stains very deeply and is usually easily located. Likewise the mucilage of the canal takes the stain readily. You may also find fertilized eggs and even young embryonic sporophytes.

On the sporophyte note character of the roots that arise from the rhizome, the scales on its surface, manner of origin of the leaves. Which is the youngest part of the rhizome? In the slide of cross section of Pteris aquilina, recognize these tissues: epidermis, chlorenchyma, parenchyma, sclerenchyma, fibrovascular bundles. With hand lens note these also on the smooth cut surface of the piece of rhizome on your table.

The spores are borne in sporangia that occur in clusters, sori, on the leaf. The form and arrangement of the sori is a mark used in the classification of the ferns. Study a single sporangium and its spores. The ring-like ridge around the capsule, known as the annulus, should be closely studied. Put some capsules in a drop of water on a slide and without covering, warm the slide over the flame of an alcohol lamp and observe opening and snapping of the annulus.

The manner of development of the sporangium is shown in a slide on each table. The young capsules with their stalks are shown arising as mere buds under the protective angle of the edge of the Maiden Hair fern leaf.

A slide shows stages in the division of the spore-mother-cells. The divisions take place to make four spores. In the first of these the chromosome number is reduced from the 2X to the X number. What can you determine as to the number of chromosomes?

Study the illustrations of Ferns in the number of the National Geographic Magazine that is in the laboratory.

Study the herbarium specimens of tropical ferns, and learn to recognize as many of the native ferns on display as your time permits.

Study specimens of fossil ferns on demonstration table.

PLATE XVII. Draw upper and lower aspects of a prothallium X6. Median longitudinal section of archegonium; of antheridium.

Draw complete plant of Polypodium vulgare. Cross section of the bracken, Pteris aquilina. Detail of a sporangium. Series of drawings to show the division of the spore-mother-cell to form spores. Series of drawings to show the development of a sporangium.

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Smith, pp. 442 - 463
Transeau, pp. 656 - 668
Sinnott, pp. 617 - 632
Holman and Robbins, pp. 497 - 516
Emerson, pp. 262 - 271
Fuller and Tippo, pp. 785-797

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CHAPTER XI
FERN ALLIES

Other Pteridophytes than the true Ferns are generally known as Fern Allies. They resemble the Ferns in the main phases of their life history but the details of structure vary widely. They are in general a more advanced group, having more reduced gametophytes and resembling those of the Seed Plant somewhat. There are four main lines of the Fern Allies: Horsetails (Equisetums), Club Mosses (Lycopodiums), Selaginellas, and Isoetes. These have had a separate descent from ancient time, probably having sprung from common ancestors or having branched one from the other in very ancient times. The two latter show the advanced condition of heterospory (two kinds of spores, small ones to produce male gametophytes and large ones to produce female gametophytes) and are therefore nearer the Seed Plants in which heterospory is the rule. This condition of heterospory, it must however be said, is not introduced here for the first time, as there are a few genera of Water Ferns, belonging in the True Fern group, that have this advanced condition.

The Equisetums are a small group of living plants, not over 30 species in number, that are the relicts of what was once an extensive race of plants growing to tree-like proportions and forming the dominant vegetation of great forests. One of the genera of this group frequently found in fossils is the genus Calamites. The fossils indicate that this genus was heterosporous.

The living Equisetums are mostly small plants a few inches to three feet in height. Equisetum giganteum is the largest species, being a tropical American and South American species that reaches the height of 30 feet. It has a slender stem and remains erect mostly by leaning on other plants. Of our own species, the best known is perhaps the Scouring Rush (Equisetum hiemale). The long cane-like stems with little or no branching are frequently seen in swampy places or on moist sandy banks. The stem is definitely divided into nodes and internodes, the internodes being fluted with distinct ridges. The leaves at the nodes have been reduced to colorless scales hardly noticeable, and the photosynthesis is carried on by the green stems. The stems have a large amount of silica impregnated in their tissues. This gives them a rough grating feel and makes them serviceable for scouring cooking utensils, a purpose for which they were gathered and dried in pioneer days. At the tip of the stem, a cone-like mass of specialized sporophylls is developed. Each sporophyll is in the shape of a short stalk at the end of which a round shield is attached. The numerous shields being applied against one another at their sides gradually assume a hexagonal shape because of the pressure of growth. Underneath each shield and attached near the edge of the shield are a number of sac-like sporangia.

When the spores mature, the tissues of the shield shrink somewhat from loss of water, leaving a crack between neighboring shields through which the spores can be sifted out. At maturity, the exine (outer spore coat) of the spore splits into long strap-like ribbons which uncurl and open out when dry but curl up again when wet. These are known as elaters. They tend to loosen up the spore mass on drying and thus facilitate dissemination and to close it down and retain it in wet weather. Half of the spores are so constituted as to develop into male gametes and the other half, female gametes. This makes it advantageous that the spores be disseminated in groups so that both sexes be represented in a colony. The elaters in opening and closing tend to link a number of spores together and thus assume their growing in colonies instead of solitary.

The gametophytes resulting from these spores are odd irregularly branched growths smaller than the prothallium of fern. It has small archegonia that follow

the typical structure. The antheridia are small pocket-like depressions in the tissue of the prothallium. The two are, as indicated above, on separate gametophytes. The sperms are multiciliate as in ferns. After fertilization the egg cell begins dividing and develops into the young sporophyte.

The Common Field Equisetum is smaller and more branched. The plant commonly seen along railways, roads or sandy fields resembles somewhat a miniature pine tree of about six inches height. It branches extensively from the nodes of the main axis and the branches in turn rebranch. The stems are all green and the leaves are mere vestiges hardly visible. We shall not find sporophylls on these plants. They are only vegetative or, as we sometimes say, sterile. If we mark the place where we see them during the summer and then return early in the spring when the first wildflowers are out, we shall see that the perennial underground stems of these plants are sending up thick unbranched shoots that are yellowish in color and do not develop any chlorophyll. They grow up rapidly like mushrooms and at their top develop the strobili with their sporangia. These are not unlike those already described for the Scouring Rush. In a few days the spores have been disseminated, the shoots shrink and wither away. Meanwhile the green sterile shoots are coming up from the rhizomes.

The Club Mosses (Lycopodiums) are somewhat more numerous as to living species than the Equisetums. They too have tree-like extinct forms that once flourished in the ancient forests. Notable among these were the genera, Lepidodendron and Sigillaria. Among those in existence today are several species that are commonly gathered for Christmas greens. They generally grow by means of long trailing stems that send up short erect shoots at intervals. The stems are abundantly provided with small green leaves. At the top of the erect shoot there develops the strobilus. The sporophylls resemble the vegetative leaves and bear a single large sporangium on the upper surface of each. The strobili are sometimes collected commercially. When put in sacs and allowed to dry out they shed their abundant spores which are cleaned and sold as lycopodium powder. It is used in pyrotechnics.

When the spores are washed into the ground, they germinate and produce a degenerate gametophyte consisting of an irregular cushion of cells with a few rhizoids on its surface and antheridia and archegonia on its upper surface. After fertilization of the egg it develops into a sporophyte. Note here that the gametophyte no longer develops any chlorophyll and has therefore lost its nutritional independence. The prothallium of fern is chlorophyllous and makes considerable growth from materials that are manufactured in its own chlorenchyma. In Equisetum there is still some chlorenchyma in the reduced gametophyte.

Selaginella approaches nearest the Seed Plants of any of the living Pteridophytes. It is heterosporous and its gametophytes are so far reduced as to resemble those of the Seed Plants. The plants resemble Lycopodium in their vegetative features. Ours are quite small and moss-like but the tropics have larger fern-like species. The strobili have two kinds of sporophylls, microsporophylls and megasporophylls, the former usually being in the upper part of the strobilus. A single sporangium is located on the upper surface of each sporophyll. The megasporangia have only four large megaspores while the microsporangia have numerous small spores.

The spores often germinate while still in the sporangium. The megaspore wall cracks and reveals that the spore has internally produced a mass of tissue which is really the female gametophyte. A few vestigial rhizoids are seen on the edge protruding from the side of the cracked spore wall. In the exposed part of the

gametophyte are developed the archegonia, entirely embedded in the tissue. The microspores likewise germinate internally, forming a sterile wall of few cells, and within this the rest of the tissue is all sperm cell tissue, which forms a large number of sperm cells. The spores may fall downward through the strobilus and some will lodge on the megasporophylls. In wet weather the wall of the microspore swells, opening the male gametophyte and allowing it to release its sperm cells. The biciliate sperm cells swim to the archegonium still held in the megaspore wall and fertilization is effected. The young sporophyte starts growth and if it falls to the ground it strikes root and a new Selaginella plant results. Often it is held in the strobilus where it dries out. Could it go into a resting state for some time and allow the embryo sporophyte to resume growth later, it would have to be regarded as a true seed.

Isoetes is a genus of plants usually growing in mud and resembling small rushes or leek. The plants are sometimes called "quillworts" because of a resemblance of the leaves to quills. At the base of each leaf it is somewhat spoon-shaped. In the hollow of this base there is found the sporangium. The sporangia are of two kinds as in Selaginella so that Isoetes also illustrates heterospory.

LABORATORY WORK ON FERN ALLIES

Fertile and sterile shoots of the Field Equisetum are supplied. Note the arrangement of nodes and internodes on each. Look for the reduced leaves. Do they still function in food manufacture? The ridges on the stem carry the fibrovascular bundles on their inside. Note that the ridges of one internode alternate with those of the next internode. Each bundle forks at the node, and two branches from neighboring bundles unite to form a new bundle that rises in the next upper internode. Study the cross sections of Equisetum stem shown on the permanent slides supplied you.

How does the Scouring Rush (Equisetum hiemale) compare to the Field Equisetum? How is it different?

Study a preserved strobilus and note the shape of the sporophylls as seen from the outside. Cut away some of the sporophylls and note their mode of attachment to the central axis. Under the shield-like outer part of the strobilus look for the sporangia. Can you tell how the sporangia split open to allow the spores to escape? Study the spores under magnification and note the elaters. Allow some spores to dry out and watch the uncoiling of the elaters.

PLATE XVIII. Draw habit sketches of Scouring Rush (Equisetum hiemale) and of fertile and sterile shoots of the Field Equisetum (E. arvense). Draw much enlarged a sporophyll as seen from the side. A group of spores much enlarged, elaters being closed in some and open in others. Make a drawing of the two gametophytes to show sex organs, as seen in prepared slides.

Three species of Lycopodium are on your table. L. lucidulum and L. complanatum are trailing forms, while L. obscurum is tree-like. The last two species have strobili while L. lucidulum has its sporophylls at the tips of shoots and they resemble the vegetative leaves. Examine the sporangium of L. lucidulum under the hand lens. Color? Shape? Crush the sporangium and make a microscopic study of the spores. Are there any markings on their surfaces? Note the lycopodium powder in vial. Rub some of it between thumb and finger to determine its smoothness.

In permanent slides supplied you the cross section of a stem of Lycopodium is shown. Note the character of the central stele with its areas of xylem and phloem. Around it is a thick cortex and on the outside an epidermis. Some cross sections of leaves may be seen around the sections in some of the slides. Look for branch fibrovascular bundles in the cortex that are on their way to supply the leaves.

Lycopodium gametophytes are so rarely found and being difficult to grow, we have none for study in the laboratory. See text for their character.

The sporophylls of Selaginella are arranged at the tip of the stem in a sort of a four-sided strobilus. Dissect out the sporophylls carefully and look for megasporophylls and microsporophylls. How can they be distinguished even with little or no magnification? Compare the two kinds of spores.

PLATE XIX. Habit sketches of Lycopodium lucidulum, L. complanatum and L. obscurum. Adaxial view of a sporophyll of L. lucidulum and the same of L. complanatum. Some spores enlarged. Cross sectional view of Lycopodium stem, showing tissues but not cell detail.

Habit sketch of Selaginella plant. Megasporophyll with megasporangium and microsporophyll with microsporangium. Side by side in same proportion a megaspore and a microspore.

REPORT 6. Write a report on Selaginella pointing out why it is the most advanced living type of the Pteridophytes.

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Smith, pp. 464 - 482
Transeau, pp. 668 - 676
Weatherwax, pp. 302 - 322
Holman and Robbins, pp. 516 - 531
Robbins and Weier, pp. 410-422

CHAPTER XII

THE PINE

Gymnosperms are the most primitive of seed plants in existence today. They probably descended from the Seed Ferns (Pteridosperms). Some of them, as for example Zamia or funeral palm of Florida, have fern-like leaves. The Maiden Hair tree (Ginkgo) has broad leaves but most others are possessed of needle leaves. In the Funeral Palm. Zamia, two kinds of strobili are produced on different plants. The megasporophyllous strobilus is a foot or more in length and each sporophyll has two megasporangia. A single megaspore functions inside this and grows into a female gametophyte. After fertilization of an egg cell in this gametophyte a young sporophyte begins development but comes to rest and remains inactive until the whole structure bounded by the megasporangial wall is subjected to the moisture of the soil whereupon the embryo sporophyte resumes growth and strikes root into the ground to form a new plant. This structure from which the plant grows is known as the seed.

The microspores of Zamia are very small. They begin germinating while still in the microsporangium and the male gametophyte has already several nuclei when the microspore is carried about by the wind. If it alights by chance on a drop of sticky fluid that is extruded from the **micropyle**, a tiny opening in the megasporangial wall, it will be drawn inside as the liquid is sucked back. Inside, it grows further and emerges from the microspore wall and grows as a parasite on megasporangial tissue. A branch grows down toward the female gametophyte and discharges two multiciliate sperm cells into a depression over the female gametophyte. The sperm cells swim about in this limited miniature pool and find the opening of the neck of the archegonium. Fertilization is effected and the embryo sporophyte begins its development.

In Zamia we have then still ciliated sperm cells as in the ferns. The microspore is definitely reduced to such small proportions as to be readily transported with its young gametophyte to the point where fertilization is to take place. In lower plants, it was the sperm cells themselves that had to exercise the locomotion necessary to reach the egg cell. Now they are borne to the female gametophyte by the microspore. Further, after the embryo sporophyte has started growth, it can come to rest for a long time, being protected by megasporangial walls in a new type of structure which we call the seed.

Pine may be used as a type of the Conifers, a large group of modern needle-leaved trees that form evergreen forests in colder regions both in northern latitudes and in mountainous areas. Some grow in pure stand in regions that are not cold, as for example the bald cypress and southern yellow pine of our southern states. Spruce, fir,hemlock, juniper, larch, cedar, redwood, and arbor vitae are others of the better known genera of Conifers. They supply about one-half of our timber as well as all of our naval stores.

The pine tree has an excurrent trunk and the branching is more or less regular from nodes. The ultimate twigs have small spur branches each of which has only 2 leaves in the Scotch and Austrian Pine and 5 in the White Pine. The sporophylls are highly modified scales on cones or strobili. They are relatively small and evanescent in the microsporophyllous strobilus but woody and durable in the **megasporophyllous** strobilus which often takes three seasons to complete its life history.

The microsporophyllous strobilus appears in the spring and produces a great mass of microspores (pollen) and then withers away. It is less than an inch in length. The sporophylls are arranged in definite cyclic fashion, the outer faces

of the scales fitting closely together so as to protect the sporangia within until the spores are mature. Each microsporophyll bears two sporangia on its under side. As the spores mature the exine is puffed out on either side so as to form two bladdery chambers on each spore. These are useful in wind dissemination of the spores. At the time of the shedding of the spores they have already germinated to form the beginning of the male gametophyte within their walls. This consists of two small prothallial cells that do not function further and the so-called antheridial cell. The prothallium thus has degenerated to two non-functional cells and the beginning of the antheridium is represented by the antheridial cell.

In this stage of development the male gametophyte is borne inside the spore wall to great distances by the air currents. In our North Woods the lakes are frequently a sulphur yellow in the spring because of the masses of pine pollen that have fallen on the water. "Sulphur showers" are at times reported consisting of this yellow pollen. Some of the pollen must by chance fall into the micropyle of the megasporangial wall that houses the female gametophyte. Inside the micropyle the male gametophyte resumes growth and its germ tube penetrates the tissues surrounding the male gametophyte and eats its way parasitically down to the archegonia of that gametophyte to effect fertilization.

The megasporophylls are hard and woody and require two or three seasons to complete their work. They are arranged in cyclic pattern about the axis of the strobilus. On the upper side of each there are developed two megasporangia. The walls of the megasporangium grow upward from the basal point of attachment but the walls do not come together completely. A small opening, the micropyle, is left. This serves as a point of entrance for the pollen grains later. The tissue of the megasporangium inside the walls which would ordinarily be expected to serve as sporogenous tissue does not develop into spores. Only one megaspore-mother-cell functions as such and the rest of the tissue serves as food for later developing gametophyte tissue. Four megaspores develop from the megaspore-mother-cell. These are not in a group like the tetrads that we saw in lower plants but they lie in a row. Three of them degenerate and only one functions to grow into a female gametophyte. Thus we see that the tendency of developing bigger, better and fewer megaspores has reached the ultimate point of producing only a single megaspore, which however is provided with such protection and food as to make its successful growth reasonably free from chance.

The megaspore germinates and grows gradually into an elliptical-shaped female gametophyte which grows at the expense of the other potential sporogenous tissue which did not form spores. This tissue is called nurse tissue or "nucellus". While the gametophyte is growing the megasporangial walls also enlarge and the nucellus itself continues growth until the whole structure reaches the size that is characteristic of the mature seed of the species of pine in question. In the edible seeds of Pinon this is about the size of a garden pea, but in most other species it is smaller.

Four archegonia are developed in the end of the gametophyte which is nearest the micropyle. Some nucellar tissue however closes these archegonia from free access to the outside. That necessitates the parasitic growth of the male gametophyte through this part of the nucellus in order that it may deliver its sperm cells to the neck canals of the archegonia. This growth is often slow, the growth (pollen tube) resting in the nucellus during the winter in some species. When the pollen tube reaches the mouth of the archegonium it discharges two sperm nuclei which enter the archegonium and one fertilizes the egg cell. It is interesting to note here that the motility of the sperm cell has been completely

lost and in the higher seed plants the same condition persists. Not only has motility been lost, but the sperm nucleus no longer is surrounded with a cell wall.

After fertilization, the egg cell begins dividing and forms cells nearest the micropylar end which are known as suspensors. Their elongation forces the lower cells of the embryo farther down into the gametophyte tissue. There these cells gradually multiply and assume specialized functions to form the primordia of root stem and leaf of the future pine tree. The root develops in such a position as to lie nearest the micropyle whence it emerges in germination of the seed. The mature seed consists of a sporophyte embryo that lies in the gametophyte tissue (now sometimes called ondosperm) which is bounded by the megasporangial wall of the previous generation sporophyte. Upon germination, the embryo sporophyte first feeds on the rest of the gametophyte (endosperm) tissue until its cotyledons can form chlorophyll and manufacture some food independently.

The advantages of the seed habit are apparent on a little thought. Since the embryo can rest a long time in the quiescent seed, it may be carried great distances by various agencies to help spread the distribution of the species. Furthermore it makes possible life of annual plants in regions that have unfavorable winter or dry seasons.

LABORATORY STUDY OF PINE

By way of introduction to Pine study the two types of strobili of Zamia. Note that the microsporophylls have a number of microsporangia on the lower surface. Examine the spores under the microscope. A prepared slide shows the microspores with their nuclei stained. It would be more accurate to speak of this as a male gametophyte than a spore, since it ceases to be a spore at the first cell division.

The megasporophyllous strobilus is much larger than the microsporophyllous. What is the shape of the outer surface of each sporophyll? How many megasporangia has each sporophyll? In order to effect fertilization, the microspore enters the integument and germinates inside to enlarge the male gametophyte. Do you find where the microspore enters? This is known as the "micropyle." Cut a median longitudinal section through the megasporangium directly through the micropyle.

Earlier in its development the megasporangium had but a single functioning spore which has already germinated within its sporangium and grown into a female gametophyte. Your section should show: a thick outer and a thinner dark inner coat (the sporangial walls or the seed integuments); the remains of the nucellus especially at the micropylar end; the large white mass like the kernel of a nut which is the female gametophyte; toward the micropylar end of the gametophyte one or two archegonia (out of a total of four).

In a prepared slide on your table you see part of the female gametophyte cut so as to show at least one archegonium. The wall cells of the venter are distinct, and only two cells remain to represent the neck. The egg cell is quite large. After fertilization it will grow into the sporophyte. Its nucleus is visible in most slides. Note that the archegonia open into a depression, the archegonial chamber. This chamber contains water at the time of fertilization and in it the ciliated sperm cells disport themselves for a brief period before entering the archegonium.

Vegetative features of the Pine:

1. Study the shoot of White Pine supplied you. Age of shoot? Note old leaf scars and bud scale scars. How many leaves in a fascicle? Note the bracts at the base of the fascicle. Terminal bud. Lateral buds?

2. The leaf. Review the tissues as seen in cross section on the permanent slide. Identify epidermis, stereome, xylem and phloem, resin ducts, chlorenchyma, chloroplasts, pith, fibrovascular bundles.

3. The stem. Review cross sections of the pine stem in slides on your table. Identify epidermis, cortical tissues, cambium ring, xylem or wood, annual rings, summer wood and autumn wood, resin ducts, pith.

Reproductive features of the Pine:

Note small size of the microsporophyllous strobilus, arrangement of its sporophylls, and shape of the sporophylls. How many sporangia do you find on each and on which are they? How does it compare with that of Zamia? Compare also the model of this strobilus and a single sprophyll. How do the sporangia open? Study spores under the microscope and compare the stained ones on permanent slides. Note the nature of the bladdery floats. How many nuclei are present at this time? What is this structure at this stage? (No longer a spore, strictly speaking). Look at the collected pollen in the vial on your table. Feel it between thumb and finger. Why must this pollen be produced in such very great numbers? Does anemophily require more or less pollen than entomophily? In some coniferous trees the microsporophyllous strobili tend to be more numerous at the lower part of the tree and the megasporophyllous at the top of the tree. What relation has this to pollination?

A museum tube on your table shows, besides the male strobili, three seasonal stages of development of the megasporophyllous strobilus of pine. The first year the cone starts its growth and rests through the winter; the second its scales open and allow the pollen to enter; the third year the seed develops and reaches maturity.

Dissect the lower sterile megasporophylls away from the cone supplied you until you come to scales that have developed megasporangia. On which side of the scale are they borne? Number? Note that a layer of tissue is prepared to peel from the scale and cling to the mature megasporangium (seed) at the time of its dissemination. All the conifers have these winged seeds. Drop some ripe seeds from as high as you can reach and note the spinning motion as they fall. What advantage does this motion give the plant?

Permanent slides show development of the pollen grains from the mother cell and mature pollen grains. Slides labeled "Pine Ovule with Archegonia" show the female gametophyte inside the megasporangial wall and the remains of some nucellus in which you may find the traces of the parasitic pollen tube. Archegonial wall, neck cells, and the large egg with prominent nucleus should be identified.

Dissect out a mature pine seed to identify the same structures, further developed, that you find in the slide.

Study display of other species of coniferous cones. Learn to identify as many by their cones as your time permits.

Review character of the leafy shoots of our common conifers, specimens of which are on display.

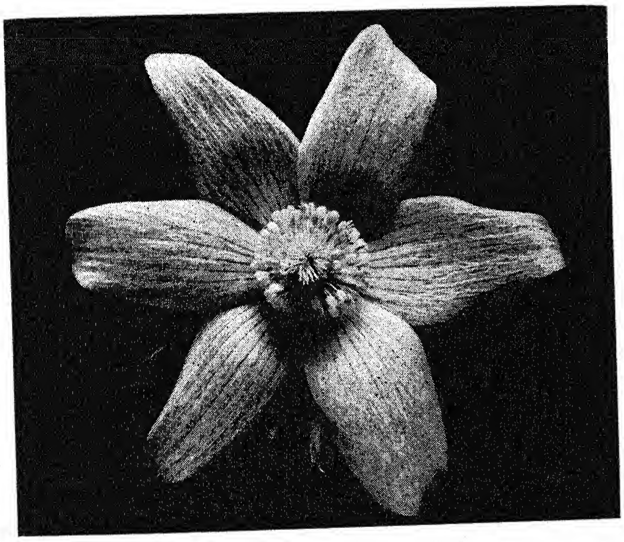
PLATE XX. Draw microsporophyllous strobilus of Pine and the three seasonal stages of the megasporophyllous strobilus. Much enlarged, adaxial and abaxial view of microsporophyll. Several microspore-mother-cells in different stages of division. Mature microspore at time of shedding to show air bladders and the nuclei of the young gametophyte.

Draw adaxial and abaxial views of megasporophylls. From permanent slide, section through megasporangium to show megasporangial walls, the nucellus, female gametophyte, archegonia, egg cells. In the nucellus near the micropyle, look for "worm track" traces where the parasitic male gametophyte (pollen tube) has eaten its way toward the archegonia.

REFERENCES FOR READING

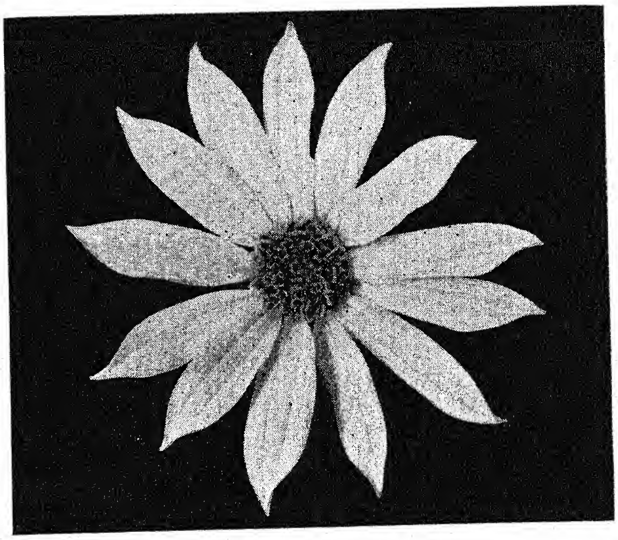
Smith, pp. 483 - 512
Transeau, pp. 678 - 687
Weatherwax, pp. 323 - 336
Sinnott, pp. 633 - 650
Holman and Robbins, pp. 537 - 557
Emerson, pp. 272 - 280
Robbins and Weier, pp. 434-446
Wilson, pp. 426-432

ERYTHRONIUM A MONOCOTYLEDONOUS TYPE



PASQUE FLOWER
A PRIMITIVE DICOTYLEDONOUS TYPE

SUNFLOWER
AN ADVANCED DICOTYLEDONOUS TYPE



CHAPTER XIII
ANGIOSPERMS

In the preceding chapter we considered the Gymnospermous seed plants, in this we shall pay attention to the Angiospermous seed plants. As the names indicate, the seeds are exposed in the former and enclosed in the latter. In the pine the two seeds lie on the upper surface of the cone scale or megasporophyll. In all the Angiosperms it is as if this cone scale had curved over sharply until the edges met and then grown together to form an enclosing structure for the protection of the megasporangium and later seed. This is actually how the fruit of Angiosperms is formed. The fruit may be simple and consist of but one megasporophyll as in Larkspur or in Crowfoot, or more than one megasporophyll may enter into the making of a compound structure, the parts often fusing so intimately as to make it difficult to distinguish the component parts. In most lilies there are three megasporophylls represented in the fruit, in roses and their relatives there are generally five megasporophylls. These megasporophylls are called "carpels" and the unit structure resulting from the fusion of several of them as well as a single one as in Larkspur is known as the "pistil" in the flower, the lower part of which later develops into the fruit. In brief, then, the seeds are always exposed in the Gymnosperms and inclosed in the Angiosperms.

In addition to tracheids that carry water in the Gymnospermous stem, the Angiospermous stem presents tracheae, which are far more efficient and rapid carriers of water. In consequence the Angiosperms are successful in situations where rapid transpiration is carried on as in the tropics. They have distributed themselves much more widely over a greater variety of geographical situations than their forerunners.

While the Gymnosperms are exclusively pollinated by agency of the wind, the Angiosperms have been particularly successful in forming alliances with the insect world and thus achieving pollination in a most astonishing variety of ways. The evolution of many flowering plants and associated insects has gone hand in hand. This has no doubt helped contribute to the very great variety of species that the Angiosperms present in comparison to the relatively few species of Gymnosperms.

This group of plants is often known as the "flowering plants." It depends of course on definition, but we incline to regard the strobili of the Gymnosperms as flowers in as truly a botanical sense as those of this division. As we have learned in our general study of the flower not considered from the evolutionary point of view at the close of last semester, a complete flower consists of two sets of accessory organs, the sepals and petals, and two sets of essential organs, the stamons and carpels. But not all flowers are complete. Some lack entirely accessory organs and in some that are monoecous or dioecous, there is only one kind of essential organ present, as in the case of the flowers of willow. The same is true of the pines and their relatives which have flowers (strobili) that have but one set of essential organs and lack the accessory organs. There is then really more similarity than difference in these two great divisions of the seed plants.

Let us examine the two kinds of essential organs, the stamen and the carpel, which are the microsporophyll and megasporophyll if we may retain the terminology brought up through the evolutionary types we have been studying. First the microsporophyll, as for example in the liliaceous flower. It has a long stalk, the "filament" at the top of which is inserted the anther or sporangium. There are four sporangial chambers in it as may be ascertained by cutting it across. As it approaches maturity there are differentiated in each of these

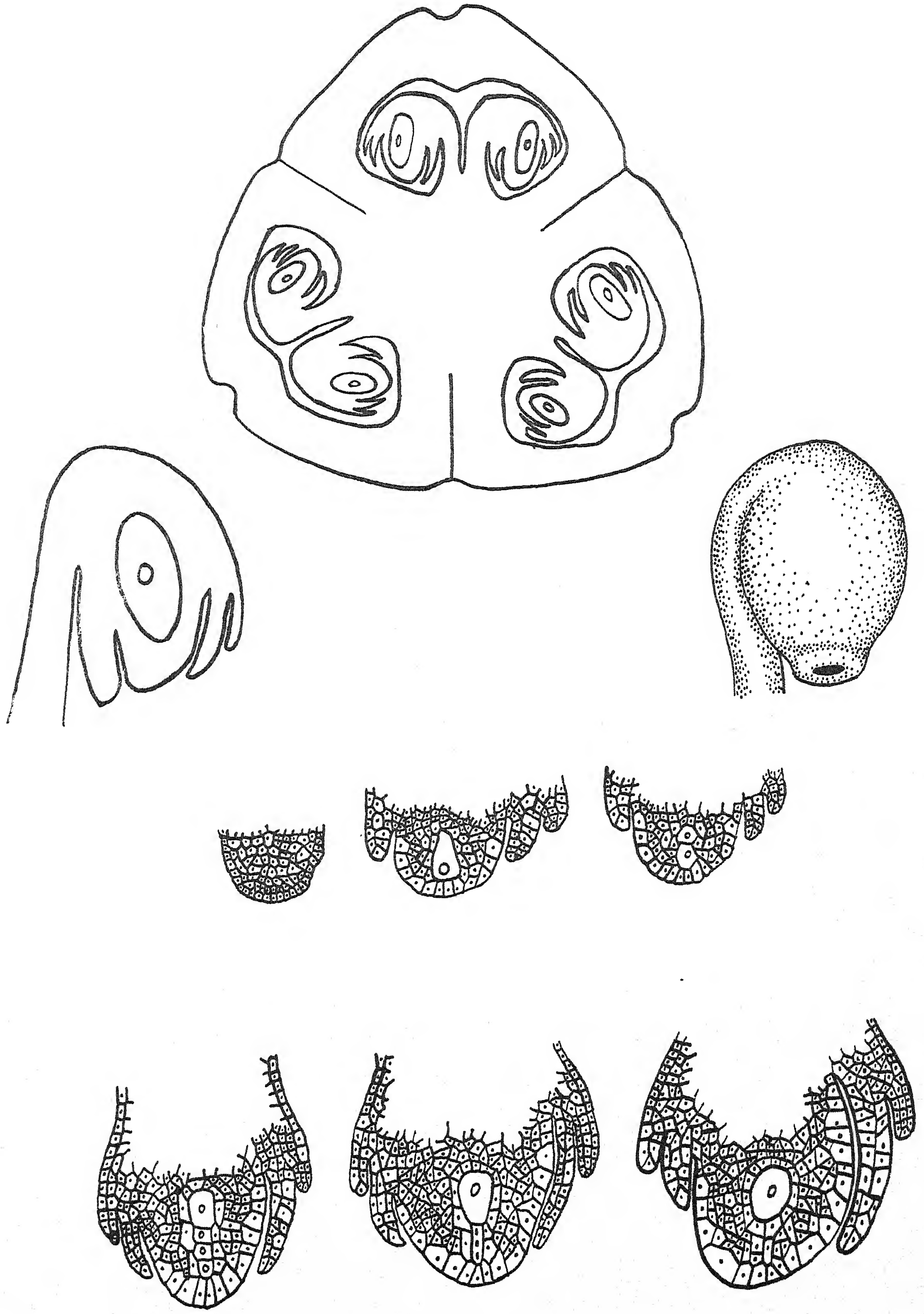
sporangial chambers the spore mother cells, each of which is destined to divide twice to form four spores (pollen grains). A layer of cells surrounds these spore-mother-cells which is homologous to them but which is not used to develop spores. It is used as nurse tissue that feeds the developing spore-mother-cells. It is known as the "tapetum." The walls of the anther have chlorenchyma tissue under the epidermis which may or may not function depending on the species of plant. We must not forget the foliar nature of the stamen, the filament representing the midrib and petiole while the anther part is the laminar part folded over and grown together and in fact modified out of recognition. It enfolds the sporangia which are exposed in ferns and Gymnosperms.

When the microspore-mother-cells divide twice the chromosome number is reduced from the 2X number to the X number. Thus in Pondweed the number is reduced from 12 to 6, in onion and other lily family representatives from 16 to 8; Lilium itself, from 24 to 12; horned liverwort, from 8 to 4, etc. The divisions are either simultaneous leaving the spore with three plane walls or successive leaving the spore with two plane walls. The former is most common. The spores develop a heavy exine which may be reticulate, spiny, warty, or sculptured in various designs.

At time of dissemination of pollen, the spores have already germinated and produced the two first cells of the male gametophyte: the smaller generative cell and the tube cell which takes up the bulk of the space within the spore wall. It is carried by wind, insects, or other agencies to the stigma, which is the receptive surface of the pistil. Here it encounters secreted chemical stuffs which are stimulative to its growth and it sends out a filamentous growth usually through a thin germ pore in the exine. This filament or pollen tube (really the male gametophyte) eats its way through the stigma and the style down to the ovary where it is chemically attracted to the micropyle of the ovule. It enters and reaches the female gametophyte to discharge its two sperm nuclei to effect fertilization.

When the microspores become wet, they often burst and are spoiled. Thus in apple orchards pollination is often defeated by continuous rains which therefore prevent the "setting" of the fruit. Very few plants can bear to have their pollen wet. Most of the pollen is of course wasted in falling in places other than the stigmatic surface of the pistil. Insects eat pollen in many cases but usually manage to carry enough from flower to flower to pay for their fare. As a result of the many vicissitudes to which the pollen is subject, it forms in tremendous quantities, more being formed in anemophilous flowers than in entomophilous ones. The surprising thing is that pollination does succeed in so large a percentage of cases. Consider for example the fact that most ears of corn have all their kernels set. This means that every one of the threads of the corn silk has managed to catch at least one pollen grain, that it has grown out into a parasitic tube which has successfully eaten its way the full length of the silk, often over a foot, and has delivered its two sperm nuclei into the female gametophyte in order that fertilization might be effected and the ovule stimulated to develop into the mature grain containing embryo and endosperm.

A carpel may have one or more megasporangia (ovules). The ovule resembles that of Pine. Two seed coats or megasporangial walls enclose a nucellus which is really sporogenous tissue that has not formed spores. In its early development, a single cell was set aside as a spore-mother-cell. It divided to form four spores in a row. Three of these degenerate while the one nearest the base or farthest from the micropyle develops into the single functioning megaspore. It germinates in site and forms the female gametophyte, a much reduced structure



Gage

now consisting of but eight cells, or rather only nuclei. These lie in groups of four at the two ends of the gametophyte for a time, then, one from each group proceeds to the center where they fuse to form the endosperm nucleus. The three left at the basal end surround themselves with walls and are known as antipodal cells. They have no particular function. The three at the micropylar end differentiate into an egg cell and two synergids, the latter being merely nurse cells to the egg cell. In this state the pollen tube arrives and discharges its two sperm nuclei. One of them unites with the egg cell to make the 2X fertilized egg cell, the start of the new embryo sporophyte. The other nucleus fuses with the endosperm nucleus in the middle of the gametophyte. This is already 2X after the fusion of the two cells from either end. The fusion with it of the sperm nucleus makes it 3X. It serves to form the endosperm which will feed the young embryo during the early stages of its development or during the early stages of its germination.

The ovule, after fertilization, increases greatly in size, the megasporangial walls enlarging to form the seed coats of the mature seed. The endosperm nucleus develops a mass of tissue which is eaten at once by the enlarging embryo in non-endospermous seeds but which is stored in the seed till germination in endospermous seeds. The fertilized egg grows into the embryo with the primordia of root, stem and leaf. The seed may rest from a month to many years, depending on the species, before it resumes growth in germination.

As the seed is stimulated to growth by fertilization, so also is the ovary wall and sometimes additional tissues stimulated to grow into the fruit. In most cases the fruit will not develop if the seed is not also developing. Notable exceptions are banana fruits and other seedless fruits of various types. In some cases the receptacle of the flower takes a part in forming the fruit, as is the case in the apple, strawberry, fig, etc.

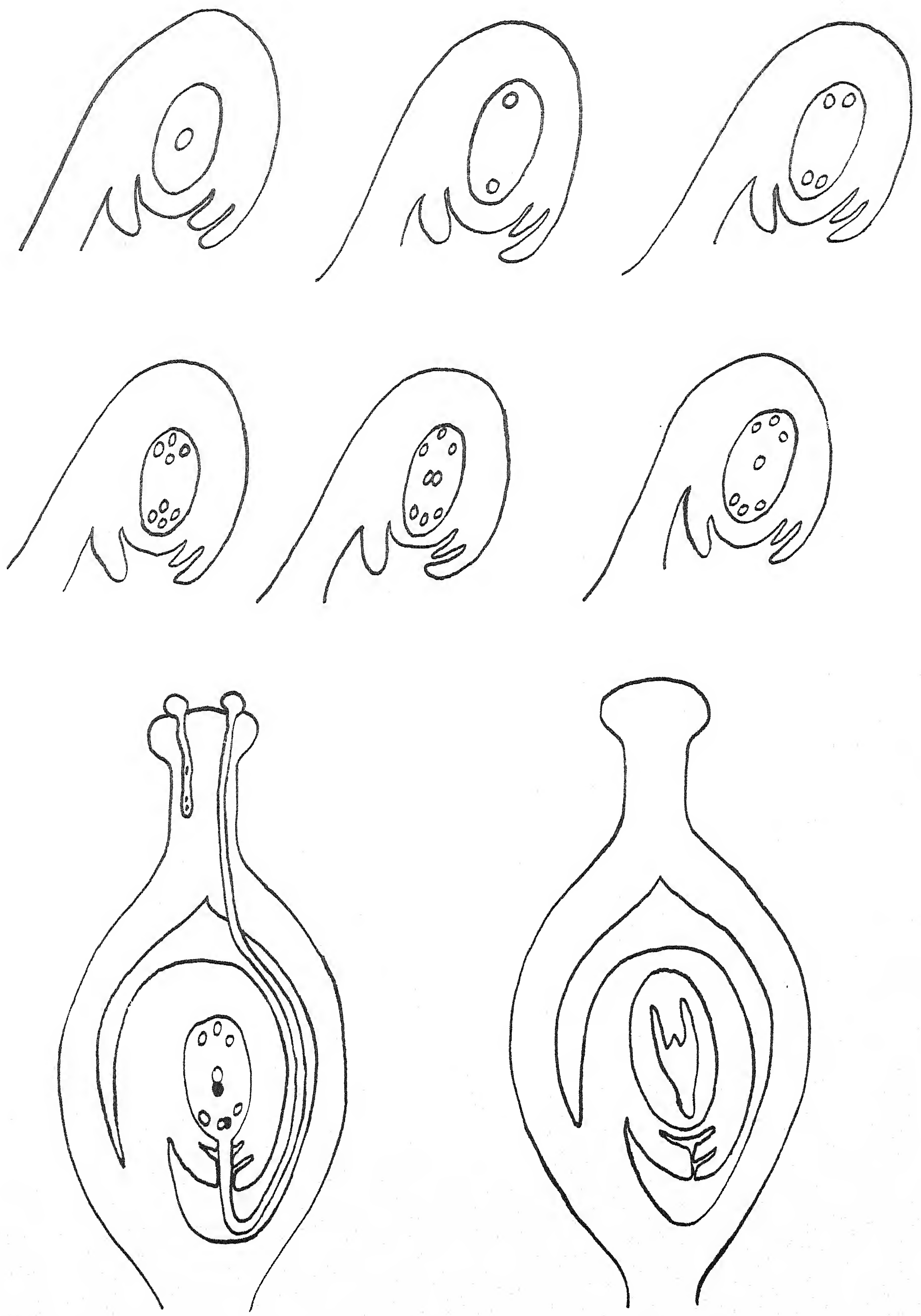
The life cycle of an Angiosperm is in one sense simple and in another sense complex. If one keeps in mind its essential adherence to the evolutionary scheme of alternating generations of gametophytes and sporophytes, with the gametes and the spores as the essential reproductive cells, however, there are many variations and extreme reductions of structures which make the cycle seem more complex than any of the preceding ones we have studied. The student would do well to refer to such a cycle diagram as that given on p. 404 of Robbins and Rickett.

LABORATORY STUDIES OF ANGIOSPERMS

As a type of the Angiosperms we may select for study the cultivated Tulip. Note character of the bulb. It consists of a plate of stem tissue to which the roots are attached and from which arise short fleshy modified leaves, the scales which serve for food storage. From the center of this underground stem arises also the elongated aerial stem. What type of veining occurs in the leaves? What is the character of the margins of the leaves?

Study the flower in detail. It contains two whorls of three each of colored perianth leaves. In most plants the outer set is green and is known collectively as calyx (consisting of sepals) and the inner alone is known as the corolla (individually as petals). These organs are accessory. The essential organs are the carpels and the stamens. How many of each kind?

The stamen is really a microsporophyll. It consists of a filament and an anther. The anther contains the sporangia. Cut a young anther across and find



Gage

how many sporangia there are. What is the nature of the microspore (pollen grain) as seen under the microscope?

The three carpels are really megasporophylls. They have fused to form a single pistil. The top of this is somewhat enlarged and papillate to form the stigma which receives the pollen. It is connected with the ovary below by a slender portion, the style. Cut a cross section of the ovary and note that each carpel has a cell in which occur two rows of megasporangia (ovules). Each of these is destined to grow into a seed and the ovary wall will form a fruit. Examine the mature fruits supplied you.

Developlent of pollen and ovule. The steps in the development of the microspore and female gametophyte of the most typical Angiosperm flowers is diagrammed on the board. These should be copied in your notes.

Study in permanent slides the development of the megaspore and female gametophyte of Lily. Compare the photomicrographs of the same. Lily does not follow the typical development as shown in the diagram on the board. Instead of the megaspore-mother-cell dividing to form four megaspores, it forms the female gametophyte directly. This is then another step in the reduction of structures to simpler terms that we have noted throughout the evolution of the gametophyte. In the slide labeled, Lilium, Archesporial Cell, note that the sections are like those you made of tulip. How many "cells" are in the ovary? How many carpels make up the pistil? How many rows of ovules are side by side in each cell?

Select a section where the ovule has been cut exactly through the middle, so as to show a large cell with prominent nucleus. This is the megaspore-mother-cell. The seed coats can be made out as growing around the nucellus and almost closing together at the micropyle. On the side of the funiculus the outer seed coat is fused with the funiculus, so that you can see only one coat. How many layers of cells in thickness is the nucellus?

In the slide labeled, Lilium, Embryo Sac, find an ovule that shows this original large megaspore further developed so as to show more than one nucleus. Now it is a female gametophyte, and since the embryo sporophyte begins its development in this structure, it has been called the "embryo sac." When mature it has eight nuclei. You will perhaps not find all eight in one section. Two of these fuse to become the endosperm nucleus, three become antipodal cells, and of the three at the micropylar end, two become synergids. The other is the egg cell which is fertilized by the sperm nucleus from the pollen tube and grows into cotyledons, epicotyl and hypocotyl of the embryo sporophyte.

The slide labeled, Lilium, S.M.C. Prophase, shows cross sections of an anther. How many sporangia (pollen chambers) has it? Note the microspore-mother-cells surrounded by a layer of cells that were potentially the same type of cells but that serve as nurse tissue to the growing microspore-mother. They are the tapetum. Outside this are several layers of cells flattened as wall cells, and beyond this the chlorenchyma just below the epidermis.

Other slides of the Lily anther show different stages in the two divisions of the microspore-mother-cell. Study this process in detail to the formation of the mature pollen grain. How does the anther of Lily open when mature? Would you expect each sporangium to open separately? What is the nature of the wall of the pollen grain? Number of cells at time of dissemination?

PLATE XXI. Draw habit sketch of Tulip plant, including longisection of bulb. A stamen X4 and beside it a cross section of the anther in same proportion

to show the locules.

Draw the entire cross section of Lilium anther in large outline, as large as the page size will permit. Fill in cell detail of one segment of the side of a loculus, showing epidermis, chlorenchyma, wall layer, tapetum and microspore-mother cells.

Draw as many other stages in the division of the microspore-mother-cells as you can find in the different stage slides supplied you.

Draw a mature pollen grain.

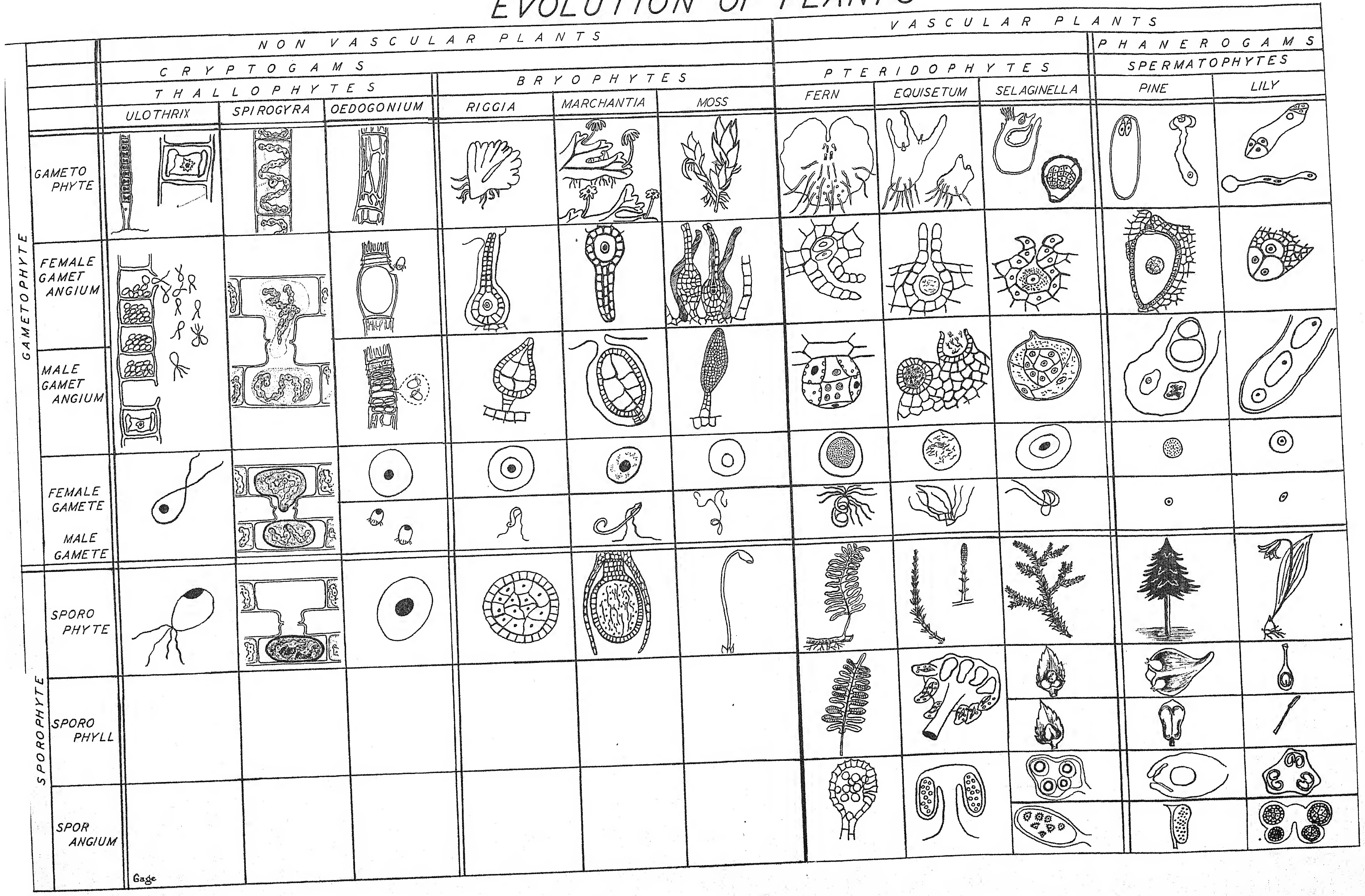
In a slide of the cross section of a young ovary, note the three carpels and in each a pair of megasporangia or ovule primordia. The prominent megaspore may not appear in each case at the level that your section shows, but at least one should show well in each section. Move the slide to the different sections to find the best view of this large cell.

Be sure you understand what is represented in the drawings on pages 70 and 72. Then label these drawings.

REFERENCES FOR READING

Smith, pp. 513 - 536
Transeau, pp. 687 - 692
Weatherwax, pp. 337 - 353
Sinnott, pp. 651 - 661
Holman and Robbins, pp. 286 - 293
Wilson, Chapter 14

EVOLUTION OF PLANTS



GLOSSARY

Accessory organs - In reference to organs of a flower: sepals, petals and nectaries, in contrast with the essential organs.
Aecidium (a) - Cup-like structure of rust bearing the aecidiospores. In wheat rust they occur on the leaves of barberry. The aecium.
Aecidiospore - One of the forms of spores in the life cycle of rust.
Agaric - Basidiomycete in which the spores are borne on the surface of gills.
Alga (ae) - Chlorophyllous thallophyte.
Alternation of Generations - Succession of single chromosome (X) and the double chromosome (2X) plants, the one produced from a spore, the other from a fertilized egg.
Anemophilous - Pollinated by wind-carried pollen.
Angiosperm - Seed plant that has the seeds enclosed in a structure developed from the ovary wall.
Annulus - Literally, a ring. Refers to the part of the pileus of a mushroom that remains as a collar about the stipe when the pileus opens. Also the ridge of thick-walled cells surrounding the sporangium in most of the true ferns.
Antheridium (a) - Male gametangium producing sperm cells in plants lower than the seed plants.
Anthocyanin - Organic compound conditioning the color of many plant parts.
Antibiotic - A bactericidal substance secreted by fungi.
Antipodal - The end of an embryo sac opposite that in which the egg cell rests.
Apical growing point - Point of meristematic tissue at tip of root, stem, or of a prothallium.
Archegoniophore - Specialized structure of gametophyte in liverworts which bears the archegonium.
Archegonium - Female gametangium of Bryophytes and Pteridophytes.
Ascus (i) - Sac-like structure in which the spores of ascomycetes are borne.
Ascomycetes - Group of higher fungi having perfect-stage spores borne in an ascus; conidia are often produced in diverse ways.
Ascospore - A perfect-stage spore of an Ascomycete.
Asexual reproduction - Reproduction that does not involve gametes and the union of two cells with attendant mingling of hereditary factors.
Auxospore - A spore resulting from a diatom that has become too small from repeated division and that sheds its walls and grows to a large size when it again resumes silicious cell walls.

Bacillus (i) - Form of bacterium more elongated than a coccus-form and not curved or spiral.
Bacterial nodules - Enlarged growths on roots of leguminous plants caused by a species of bacteria.
Basidiomycete - A higher fungus that produces its perfect stage spores externally on a club-shaped structure to which they are held, usually in fours, by sterigmata.
Basidiospore - Perfect stage spore of a Basidiomycete, borne on a basidium.
Basidium - A club-shaped structure bearing the perfect-stage spores, usually in fours, in the Basidiomycetes.
Bordeaux mixture - Fungicide discovered near Bordeaux by Professor Millardet as effective against downy mildew of grape. Subsequently shown to be useful in combating many other plant diseases. Contains lime and sulphur.
Bryophyte - A cryptogam having archegonia but lacking a vascular system. Includes mosses and liverworts.
Budding - A type of cell division in which the new cell forms by a bulging of a protuberance from the parent cell which then grows to adult size.

Bulb - A group of modified fleshy leaves or leaf parts enfolded so as to make an apparently solid structure usually more or less globose in shape.
Bulbils - Small bulb-like storage structures of moss protonema.

Calamites - An extinct race of plants related to Equisetum forming an important element of the flora in Carboniferous times.
Calyptra - A cap-like structure on a moss capsule which is the result of the growth of the upper part of the archegonium.
Calyx - Outermost series of perianth leaves of a flower, the leaves (sepals) being either separate or united.
Capillitium (a) - Sterile hair-like tissue formed among the spores of Myxomycetes and some of the liverworts which is useful in gradual spore dissemination.
Capsule - The spore-containing part of a liverwort or moss sporangium.
Carpel - A megasporophyll of a flowering plant forming a simple pistil in some flowers but more often united with others of its kind to form a compound pistil.
Carpophore - A fruit-body bearing perfect-stage spores in Ascomycetes or Basidiomycetes.
Coccus (i) - Type of bacterium having spherical cell form.
Coenocyte - A thallophyte lacking walls to separate the component cells from each other.
Chlamydospore - One of the spores giving the powdery appearance to smut balls. They are formed by segmentation of the hyphae and thickening of their surrounding walls.
Chlorophyceae - Large group of algae, principally fresh-water, characterized by the green color which is not masked by any accessory pigments.
Cilia - Hair-like prolongations of protoplasm from a cell which, by their movements, are able to propel the cell through the water.
Close-conjugation - Type of union of the gametangia in Spirogyra and some of its relatives in which the uniting gametangia are neighboring cells of the same filament.
Colony - A group of cells of certain of the lower algae which remain united in a definite pattern but show no division of labor among themselves.
Columella - The central axis of vegetative tissue in the spore capsule of a myxomycete or moss.
Compositae - Highest family of Angiosperms in which the florets are united in a common head.
Conceptacle - A sunken chamber beneath the surface of the fruiting tip of Fucus and related algae in which are produced the antheridia and archegonia. It is a modified cryptostoma.
Conidia - Conidiospores - Powdery asexual spores produced principally in Ascomycetes, often in great quantities.
Conidiophores - Stalk-like hyphae from the tips of which the conidia are abstricted.
Conjugation - Sexual union of similar gametes in Desmids and the filamentous algae of the Spirogyra type.
Conjugating tube - The tube through which the gametes are conducted in the process of conjugation of Spirogyra and its relatives.
Corolla - Innermost series of perianth leaves of a flower, the leaves (petals) being either separate or united.
Cotyledon - One of the first leaf-like structures (seed leaves) in a seedling of a flowering plant.

Decay - Consumption of organic matter by bacteria or fungi.
Diatomaceous earth - Accumulated silicious cell walls of diatoms occurring in large underground deposits in certain parts of the world. It is mined and used commercially.

Diatoms - Algae characterized by symmetrical silicious cell walls that fit together in pairs like the halves of a pill box.
Dichotomous - A type of branching in which the two branches are equal.
Digitate - Resembling the extended fingers of a hand.
Dioecious - Male and female elements produced on separate plants.

Egg cell - Female gamete.
Elater - One of the hygroscopic appendages of Equisetum spores. Also strips of sterile hygroscopic tissue among the spores of the capsule of Marchantia and related liverworts.
Embryo - Earliest stages of the development of a plant. In the case of seed plants it represents the period from the first division of the egg cell to the young plant resting in the mature seed.
Embryo sac - Female gametophyte of seed plants in which the egg cell starts the development of the embryo.
Endosperm - Food material stored in the seed other than that held in the cotyledon.
Entomophilous - Pollinated by insect pollen carriers.
Exine - Outer cell wall of a spore.

False branching - Branching of filaments of certain blue-green algae due to internal pressure causing the row of cells to buckle and burst out of the side of the gelatinous sheath.
Fermentation - Digestion of sugars by bacteria or fungi resulting in the production of alcohol and carbon dioxide.
Fern allies - Horsetails, club mosses, quillworts; groups of plants closely related to the true ferns.
Fertilization - Fusion of gametes. The accompanying fusion of their nuclei is usually distinguished as fecundation.
Filament - A thread-like series of cells common to many algae.
Fission - Division of a parent cell to form two daughter cells when nuclei are lacking as in bacteria and blue-green algae.
Flower - A modified shoot of a Spermatophyte which contains either one or both kinds of sporophylls with or without accompanying perianth leaves.
Foot - The basal part of a fern embryo sporophyte which absorbs water and nutritive material from the gametophyte.
Fossil - Remains of an ancient plant or animal in the form of imprint in shale, petrifaction, calcareous impregnation, or unmodified but preserved in tar or other preserving substance.
Frond - The leaf of a fern.
Fruit - Matured megasporangial (ovary) walls with or without accessory tissues.
Fungus (i) - A thallophyte lacking chlorophyll.
Fungicide - Chemical substance used to combat disease producing fungi.
Funiculus (i) - The stalk of an ovule which becomes fused with the side wall in the case of an anatropous ovule.
Fusion - A uniting of cells or tissues. In fecundation fusion of the nuclei involved takes place.

Gametangium (a) - An enclosure for gametes. A term applied especially to structures containing isogametes.
Gamete - A reproductive cell that must fuse with another reproductive cell to form a zygote.
Gametophyte - One part of the life history of a plant that exhibits alternation of generations. It is the gamete-producing phase.
Gelatinous matrix - The secretion of gelatine with which cells of blue-green algae and certain other thallophytes are surrounded.
Gelatinous sheath - A firm gelatinous layer surrounding cells or filaments of blue-green algae.

Gemma (ae) - A vegetative reproductive body produced in cup-like structures of Marchantia or related liverworts.
Gemmae cup - A structure in which propagating bodies (gemmae) are produced in Marchantia and related liverworts.
Genus (genera) - A category of plant classification higher than the species and lower than the family. The first word of a scientific name represents the genus name.
Germination - The start of growth of a spore or of a seed.
Gill - One of the thin plate-like lamellae on the under side of the pileus of a mushroom.
Girdle - The middle band representing the region of overlap of the two halves of a diatom wall.
Gymnosperm - A spermatophyte lacking a developed ovary wall to enclose the mature seed. Literally "naked seed."

Haustorium (a) - An absorbing organ developed by a parasite to extract nutritive material from its host.
Heterocyst - A larger cell, usually less highly colored, in a chain of cells of Nostoc or other related blue-green algae, the function of which is not well understood.
Heterogamete - A gamete that differs in size and motility from the gamete of the opposite sex.
Heterospory - Condition in which a plant produces small spores that develop into male gametophytes and larger spores that develop into female gametophytes.
Heterotrophic - Opposite of autotrophic. Said of a plant that depends on other plants or animals for its food.
Hold-fast - A root-like organ that fastens an alga or fungus to the substratum.
Homologous - Similar in evolutionary history.
Homologues - Structures that have a similar evolutionary history.
Host - A living plant or animal that supports a parasite.
Hyaline - Colorless.
Hymenium (a) - The layer of tissue in the carpophore of a basidiomycete in which basidia are borne.
Hypertrophy - Abnormally rapid or large growth.
Hypha (ae) - A thread-like unit of a fungous mycelium.

Imperfect Fungi - A group of fungi reproducing by conidia which have no known perfect stage for the production of ascospores.
Indusium - A shield of tissue assuming various forms which protects the sporangia of a fern.
Inoculum - Material which serves as the source of infection by a parasite.
Intercellular - Occurring between the two walls of neighboring cells.
Intine - The inner wall or coat of a spore.
Intracellular - Occurring within the confines of the wall of one cell.
Isogamous - Having similar gametes without sexual distinction.
Isthmus - The connecting part between the two symmetrical halves of the cell of a desmid.

Kelp - Popular name for any large Brown alga.

Leguminous - Referring to the family of plants to which belong beans, peas, clover, and similar plants.
Lepidodendron - An extinct genus of trees related to the club mosses of today.
Lichen - A thallophyte having a plant body made up of a fungus and an alga living in symbiosis.
Liverwort - A bryophyte having a prostrate ribbon-like gametophyte.

Megasporangium (a) - Enclosure containing megaspores; found in heterosporous plants.
Megaspore - The larger of the two types of spores produced by a heterosporous plant. It develops into the female gametophyte.
Megasporophyll - A modified leaf bearing the megasporangia. In flowering plants it is the carpel of the flower.
Micropyle - Small opening at the distal end of the ovule left by the failure of the wall or walls to close during development. The place of entrance of pollen in the Gymnosperms and of the pollen tube in most Angiosperms.
Microspore - The smaller of the two kinds of asexual spores produced by heterosporous plants, giving rise to the male prothallium. i.e., pollen grain of seed plants.
Microspore-mother-cell - A cell in the microsporangium from which four microspores result by two divisions, one of which is a chromosome reducing division.
Microsporophyll - Modified leaf bearing the microsporangium. In flowering plants it is known as a stamen.
Mid-dorsal groove - Depression along the middle of a liverwort thallus in which the archegonia and antheridia are borne.
Mitosis - Orderly process of nuclear division in which the chromatin material is distributed equally and of same hereditary quality to the two daughter nuclei.
Monoecious - Having male and female elements on the same plant, but, in the case of Spermatophytes, not in the same flower.
Moss - A bryophyte having leaf-like scales on the gametophyte and a highly organized sporangium in the sporophyte.
Motile - Having the ability to move by its own power.
Multiciliate - Having many cilia.
Mycelium - The aggregate mass of hyphae of a fungus.
Mycophagist - One who eats mushrooms.
Myxomycete - A chlorophyll-less thallophyte having naked motile protoplasm in one stage of its development.

Nucellus - Tissue surrounding an embryo plant in a seed which is consumed in nourishing the enlarging embryo.
Nucleus - Central organized body of a cell which carries the material that determines the heredity of the cell.

Oogonium - Sexual organ of a heterogamous thallophyte that produces the egg cell or cells.
Oospore - The fertilized egg cell of an alga or fungus.
Operculum - Lid-like structure closing a moss capsule.
Ostiolum - Small opening in sporangium of certain fungi from which the mature spores issue. Also, the opening of a conceptacle of fucus.
Ovule - A megasporangium of a seed plant. From it develops the seed.

Paraphysis (es) - Filamentous structures found among the antheridia and archegonia of mosses. Also, sterile hyphae standing among the asci or basidia of a fungus.
Parasitic - Living on another organism from which nutriment is derived.
Parthenogenesis - Development of an embryonic plant from an egg cell without the process of fertilization.
Pathogenic - Producing a diseased condition. Said of parasites.
Penicillin - Antibiotic substance produced by Penicillium notatum and other species that destroys bacteria.
Perianth - The aggregation of modified leaves surrounding a flower consisting of calyx and/or corolla.
Periderm - Outer membrane covering a puffball.

Peridiole - Small spore-containing structure enclosed in the fruiting body of a bird's nest fungus.
Peristome - Aggregate of the tooth-like structures surrounding the opening of a moss capsule. They vary in number in different species: 4, 8, 16, etc.
Perithecium (a) - The fruiting body of a group of ascomycetes, among which are the powdery mildews.
Petal - One of the modified leaves of the inner series of the perianth of a flower.
Phloem - The food-conducting tissue of a vascular plant.
Phycocyanin - The accessory pigment giving the bluish color to many blue-green algae.
Phycoerythrin - The accessory pigment giving the red color to red algae.
Phycophaein - The accessory pigment giving the brown color to brown algae.
Pigment spot - A reddish colored light-sensitive bit of protoplasm in the cell of some unicellular algae.
Pileus - Cap-like portion of a mushroom which bears gills on its under side.
Pinna (ae) - A division of a fern leaf.
Pinnule - A division of a pinna of a fern leaf. Also a subdivision of the same.
Plasmodium - The aggregate of the naked protoplasm which constitutes the plant body of a myxomycete in its vegetative stage.
Plurilocular - Having many unicellular chambers in a sporangium, as, e.g., in Saprolegnia.
Pollen - A microspore of a seed plant.
Pollen tube - The germ tube issuing from a pollen grain to convey the sperm nuclei to the egg cell.
Polypore - A basidiomycete bearing its basidiospores in a hymenium that lines the inner surface of pores borne in the fruiting body.
Primordium (a) - The first undifferentiated tissue from which an organ is to develop.
Progamete - Club-like hypha end of a zygomycete (as, e.g., bread mold) at the tip of which a gamete forms by the development of a cross wall.
Prothallium - The gametophyte of a liverwort.
Protonema - The gametophyte of a true moss, resembling algal filaments.
Pseudoparenchyma - Densely woven mass of hyphae producing a fungous tissue that resembles a true parenchyma.
Pustule - A group of fungus spores formed just beneath the surface of the host tissue.
Pycnidium (a) - A structure embedded in the host tissue producing sperm-like cells in rust.
Pycniospore - Cell produced in the pycnidium.
Pyrenoid - Center of starch manufacture in a chloroplast.

Rachis - Main axis of a grass inflorescence. Also, the middle stem-like part of a compound leaf.
Ramify - To branch.
Receptive spot - The specialized point on the surface of an egg where the sperm cell penetrates.
Relict - A living species most of whose relatives are extinct.
Reticulate - Net-veined or net-like.
Rhizoid - A root-like structure of a gametophyte.
Rhizome - An underground stem.

Saprophyte - A heterotrophic plant obtaining its nutriment from dead organic matter.
Sargasso seas - Masses of plant life (with some animal life intermingled) much of which is made up of the seaweed, Sargassum.

Sclerenchyma - Very hard mechanical tissue of ferns and seed plants.
Sepal - One of the modified leaves of the outer series of a perianth of a flower.
Seta - A bristle-like outgrowth.
Sexual reproduction - Type of reproduction requiring the union of two cells (gametes) and the fusion of the chromatic material of their nuclei.
Sigillaria - Extinct group of plants related to the present-day club mosses.
Sorus (i) - A group of spores or sporangia.
Species - A category of plant classification under the genus.
Sperm cell - A male gamete.
Spirillum - A curved or spiral form of bacterium.
Sporangium (a) - Structure in which spores are developed.
Spore-mother-cell - A cell in a sporangium which, by two divisions, produces four spores.
Spore - A cell specialized for asexual reproduction.
Sporidium (a) - Type of spore produced by the germination of a teleutospore in rust.
Sporophyll - A modified leaf that has sporangia.
Sporophyte - A 2X plant. It starts from a fertilized egg and produces spores.
Stamen - A microsporophyll of a flowering plant.
Stem - The axial part of a vascular plant having the functions of support and conduction.
Sterigma (ta) - Small prolongation (usually four in number) at the end of a basidium on which develops a basidiospore.
Sterile - Not producing spores or seeds.
Style - Part of a pistil connecting the stigma and ovary.
Stipe - The stem-like part of a mushroom.
Stolon - Horizontal stem that serves to propagate a plant by growing outward along the ground and striking root.
Strobilus (i) - Literally a cone. Used in reference to the aggregations of sporophylls of Equisetum, Lycopodium, etc.
Stroma - The basic ground tissue of the fruiting body of a fungus.
Substratum - Nutrient material on which a saprophyte grows.
Suspensor - Part of an embryo of a seed plant.
Symbiosis - Condition of living together so that each of the two plants involved benefits by the partnership.
Synergid - Sister cells of the egg cell in the embryo sac of a seed plant.

Tapetum - Layer of cells surrounding the embryo sac in a seed plant which is broken down and serves to nourish the embryo sac.
Teleutospore - Thick-walled winter spore (usually two-celled) of a rust. Also called a teliospore.
Tetrad - A group of four cells that results from the two divisions of a mother cell.
Thallophyte - The lower group of plants beneath the Bryophytes.
Thallus - A plant body showing no differentiation into root, stem and leaf.
Tracheid - A water conducting cell in the xylem, usually with strong cellulosic walls, and with pores of various types in different species.
Two-X-Generation - The sporophyte. All cells have the double chromosome number.

Unicellular - Having but one cell to form the complete individual plant.
Uredospore - Repeating spores or summer spores of a rust. Red-rust spores of puccinia.

Valve - One of the halves of the silicious cell wall of a diatom.
Venter - The enlarged lower part of an archegonium of a Bryophyte or Pteridophyte. In it is found the egg cell.

"Water bloom" - Growth of blue-green algae in a lake or other body of water.

X-Generation - The gametophyte. All cells have the reduced chromosome number.
Xylem - The water-conducting (more or less woody) tissue of a stem.

Zoosporangium - A structure producing motile spores.
Zoospore - A motile spore.
Zygospore - A spore resulting from the sexual union of two gametes.
Zygote - A cell resulting from the sexual union of two gametes.